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ILLINOIS
INSTITUTE FOR
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QUALITY

COST/EFFECTIVENESS ANALYSIS OF THE ILLINOIS OZONE EPISODE REGULATION

IIEQ DOCUMENT NO. 77/04
Project No. 10.048

COST/EFFECTIVENESS ANALYSIS OF THE ILLINOIS OZONE EPISODE REGULATION (R75-4)

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Project No. 10.048

IIEQ Document No. 77/04

State of Illinois
Institute for Environmental Quality
Frank Beal, Director

May, 1977

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Opinion of the Economic Technical Advisory Committee
of the Illinois Institute for Environmental Quality

The Economic Technical Advisory Committee has reviewed the economic impact study IIEQ Document No. 77/04, entitled Cost/Effectiveness Analysis of the Illinois Ozone Episode Regulation. The Committee finds the report to be generally responsive to the requirements of Section 6 of the Environmental Protection Act and recommends that it be forwarded to the Pollution Control Board so that public economic impact hearings may be held in connection with R75-4, EPISODE REVISIONS. The regulation under study amends Chapter 2, Air Pollution Regulations, and is already in effect in accordance with Section 27(b) of the Environmental Protection Act.

It is noted, though, that difficulties in securing certain industrial cost data resulted in the formulation of assumptions which may underestimate the full impact of the regulation on that sector. The Committee urges careful consideration of these assumptions in the review of this report.

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STATE OF ILLINOIS
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Frank Beal
DIRECTOR

June 24, 1977

We are pleased to send you this
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SUMMARY

This report describes the procedures used to conduct, and the results of, a cost-effectiveness study of the Illinois episode control regulation as it pertains to ozone (oxidants), i.e., PCB R75-4. There are four episode stages that can be declared at specified ozone levels: (1) advisory, for ozone levels of 0.07 ppm; (2) yellow alert, 0.17 ppm; (3) red alert, 0.30 ppm; and (4) emergency, 0.50 ppm. No control actions are taken during advisories.

For each of the 22 emission control actions [Rule 407(b)] that can be implemented during ozone yellow alerts, red alerts, and emergencies, the study estimates (1) the "real" costs and (2) the hydrocarbon (HC) and nitrogen oxide (NO_x) emission reductions that are likely to result (i.e., the effectiveness). Estimates of the emission reductions for hydrocarbons and nitrogen oxides, which are precursors of ozone, are the best available estimates of a control measure's effectiveness. The physical relationship between reductions of ozone precursors and changes in ozone levels is not known; therefore, the effects of the episode control actions on ozone concentrations cannot be measured.

The control actions affect the operation, use, or scheduling of:

- motor vehicles;
- parking facilities;
- road repairs;
- manufacturing and other facilities having process emissions;
- electric power plants;
- offices, buldings, and other commercial and service establishments; and
- refuse burners.

The actions are grouped to reflect the various episode stages and the estimated costs and emission reductions of an advisory, yellow alert, red alert, and emergency are calculated. The annual expected cost and emission reductions of the ozone episode control program are estimated and compared to the cost and effectiveness of the state's previous ozone episode regulation, i.e., R72-6.

Annual Cost and Emission Reductions of R75-4

The annual cost of the ozone episode regulation (R75-4) in the Chicago SMSA is estimated to be $10 million. (This does not include the cost of developing action plans or enforcement and administration costs). The expected annual emission reductions in the Chicago SMSA are 1,180 tons of hydrocarbons and 970 tons of nitrogen oxide.* The cost and emission reduction effects for Illinois are estimated to be 1.48 times the Chicago SMSA figures.

Disaggregating the annual cost by cost type reveals that about 62.4% of the annual cost estimate is a result of overtime wages paid to make up for lost production time. Therefore, by far the most important assumptions in the analysis are those that affect the overtime adjustment cost.

The second most important cost components are those associated with controls on power plants: the cost of buying power, load switching, and fuel switching; the lost satisfaction to customers from reduced electricity consumption; the cost of substituting some other energy source by interruptible/economy or large electricity customers; and the savings in resources resulting from reduced power generation. The sum of these costs accounts for about nine percent of the total expected annual cost of the regulation.

The third most important cost component is that of notifying people and organizations of an ozone episode, which represents about eight percent of the total estimated annual cost of the ozone episode regulation. At least half of this is the cost of radio and TV announcements. Interestingly enough, more than 3.5% of the annual cost of the regulation is for radio and TV announcements during advisory conditions; this is a direct consequence of the frequency of advisory conditions.

The sum of the overtime, power plant, and notification costs is about 80% of the total annual cost. None of the other cost components contributes more than 5.6% of the total cost and most of them contribute less than one percent. Therefore, the uncertainties in estimating other cost components have little impact on the total annual cost estimate. This should be kept in mind when trying to interpret the results of the study. Of particular interest is the contribution of delay costs, i.e., costs due to delays in consumption

*These results are highly sensitive to the expected frequencies of the red alert and emergency stages.

of goods and services. They are less than 0.7% of the total cost. This is important because the delay cost is the primary cost component of actions that restrict shopping or recreational activities.

One important cost component is not included in the analysis: the psychic or inconvenience cost associated with the regulation. For many actions this cost could be quite significant. For example, individuals who have planned a vacation trip may experience considerable displeasure if their trip has to be canceled or delayed. Similarly, businessmen trying to meet deadlines may experience increased anxieties or frustrations if their work is stopped due to an episode. Although these costs are difficult to estimate, they are nevertheless real and should not be forgotten simply because empirical estimates of them are not available.

The most efficient control actions are those that restrict shopping and social/recreational trips (see Chapters 3 and 10). This is a direct result of the fact that the delay costs are small and that overtime is probably not required in the retail and service industries. However, the absolute effectiveness of these actions is relatively small and depends heavily on public reaction. Another very efficient strategy is the control of small incinerator operations. If waste collection operations are not affected by the closure of municipal/commercial incinerators, then controlling all incinerator operations is quite efficient (see Chapters 8 and 19). Although control of incinerators is efficient, the potential effectiveness is very small.

On the other end of the spectrum, the least efficient strategies are, in general, the actions that restrict production or trucking operations (see Chapters 9, 12, 20, 22, and 24). This result is a direct consequence of the assertion that overtime is highly likely to be required to adjust to these control actions. Although these actions are the least efficient, they have the greatest emission reduction potential of all the episode control actions.

The closing of schools (see Chapter 17) and the curtailment of aircraft departures (see Chapter 21) both have relatively high cost/effectiveness ratios and relatively small emission reduction effects.

With few exceptions, the most efficient control strategies are grouped in the yellow alert stage and the least efficient are grouped in the emergency stage. The other actions are in the red alert stage. Exceptions to this

rule are the controls on fleet vehicles (primarily trucks) and the closing of schools, which have relatively high cost/effectiveness ratios, and the closing of larger parking facilities, which has relatively low cost/effectiveness ratios. All of these activities are in the red alert episode stage. Controls on power plants become increasingly effective and costly as the episode stages advance even though the efficiency of these controls remains fairly constant.

Approximately 48.4% of the estimated annual social cost of the ozone episode regulation must be borne by the manufacturing sector; the bulk of this is overtime labor cost. The transportation and utility sectors must bear about 16.5% and 11.1% of the cost, respectively. The bulk of the transportation sector cost is also a result of overtime labor cost. The costs to utilities are primarily increased operating costs or reduced revenues. The only other group to bear more than 10% of the annual social cost is the public; this cost is primarily a notification cost. However, not included in the cost to the public are the lost satisfaction costs due to delayed or foregone consumption (these are allocated to the retail, service, and other relevant sectors) and psychic and inconvenience costs (these are not estimated).

Cost/Effectiveness Comparison of R75-4 and R72-6

The estimated annual cost of the old regulation (R72-6) is $6.30 million in the Chicago SMSA and $9.32 million in Illinois. The expected annual emission reductions are 1,820 tons HC and 2,750 tons NO_x in the Chicago SMSA and 2,690 tons HC and 4,070 tons NO_x in Illinois. Therefore, the new ozone regulation results in an estimated expected annual cost *increase* of $(10 - 6.3) \cdot 100/6.3 = 59\%$. However, the expected annual emission reductions *decrease* by 35% for HC and by 65% for NO_x. See the table on page 5 for a cost/effectiveness comparison of the two regulations.

On an annual expected value basis, the old regulation is more efficient than the new one. However, this comparison is incomplete. An in-depth analysis reveals that 64% of the expected annual HC and 31% of the expected annual NO_x emission reduction of the old regulation are from the voluntary curtailment of automobile use. For the new regulation only 19% and 16% of the expected annual HC and NO_x emission reductions, respectively, are from

Cost/Effectiveness Comparison of R75-4 and R72-6[a]

Episode Stage	Episode Ozone Levels (ppm)		Episode Length (days)	Cost ($\$10^3$)		HC Emission Reduction (tons)		NO_x Emission Reduction (tons)		Cost/Effectiveness Ratios ($\$10^3$/ton)					
										HC		NO_x		Sum	
	R75-4	R72-6		R75-4	R72-6	R75-4	R72-6	R75-4	R72-6	R75-4	R72-6	R75-4	R72-6	R75-4	R72-6
Advisory (Watch)	0.07	0.07	1	3.40	3.40	0	0	0	0	--	--	--	--	--	--
	(60)[b]	(60)	2	6.80	6.80	0	0	0	0	--	--	--	--	--	--
			3	10.2	10.2	0	0	0	0	--	--	--	--	--	--
			4	13.6	13.6	0	0	0	0	--	--	--	--	--	--
			5	17.0	17.0	0	0	0	0	--	--	--	--	--	--
Yellow Alert	0.17	0.10	1	108	108	42.3	42.3	69.3	69.3	2.55	2.55	1.56	1.56	0.968	0.968
	(4)	(22)	2	211	211	84.2	84.2	138	138	2.51	2.51	1.53	1.53	0.950	0.950
			3	313	313	125	125	206	206	2.50	2.50	1.52	1.52	0.946	0.946
			4	417	417	166	166	272	272	2.51	2.51	1.53	1.53	0.952	0.952
			5	519	519	207	207	339	339	2.51	2.51	1.53	1.53	0.952	0.952
Red Alert	0.30	0.40	1	9,320	6,230	925	695	492	363	10.1	8.96	18.9	17.2	6.58	5.89
	(1/2)	(1/5)	2	15,400	9,470	1,850	1,390	985	725	8.32	6.81	15.6	13.1	5.43	4.48
			3	21,700	11,000	2,780	2,085	1,480	1,088	7.81	5.28	14.7	10.1	5.09	3.47
			4	27,900	NA[c]	3,700	NA	1,970	NA	7.54	--	14.2	--	4.92	--
Emergency	0.50 (1/18)	0.60 (1/100)	1	36,600	36,600	1,490	1,490	953	953	24.6	24.6	38.4	38.4	15.0	15.0
Expected Annual Value Chicago SMSA	--	--	-	10,000	6,300	1,180	1,820	970	2,750	8.47	3.46	10.3	2.29	4.65	1.38
Expected Annual Value Illinois[d]	--	--	-	14,800	9,320	1,740	2,690	1,440	4,070	8.47	3.46	10.3	2.29	4.65	1.38

[a]Comparison uses base case assumption that advisory, yellow alert, and emergency control actions are identical for both regulations.

[b]Numbers in parentheses are the expected number of days that oxidant concentrations exceed the trigger levels in the Chicago SMSA per year. It is assumed this is equal to the number of times each episode stage is expected to occur each year.

[c]Not applicable since it is extremely unlikely that this condition will ever exist.

[d]The Illinois values are 1.48 times the Chicago SMSA values. This is probably high because the frequency of occurrence of each episode stage is probably less outside the Chicago SMSA.

this control action (see Chapter 3). Since the impact of this provision of the regulation may become less effective the more frequently the public is requested to reduce travel, the effect of the old regulation may be seriously undermined for the same reason its efficiency and expected annual emission reductions are high, i.e., yellow alerts are expected to occur frequently.

Furthermore, about 88% of the HC expected annual emission reduction and 96% of the NO_x expected annual emission reduction occur at relatively low ozone levels with the old regulation, i.e., at the yellow alert stage. For the new regulation all the emission reductions occur after 0.17 ppm and more than 74% of the HC and 49% of the NO_x reductions occur at levels greater than 0.30 ppm. At the red alert stage (where a major difference in the regulations occurs) the new regulation is 33% and 26% more effective in reducing HC and NO_x emissions, respectively.

The above discussion reveals that the two regulations differ in terms of expected annual cost and effectiveness. If very few manufacturing firms are affected during a yellow alert under the old rules, then the comparison of the old and new regulations based on annual expected cost and emission reductions favors the old regulation. However, this advantage could be eliminated if persons do not voluntarily curtail driving. The added cost of the new regulation seems to be a result of obtaining more protection during periods of relatively high ozone levels.

1 INTRODUCTION

On March 21, 1975, the Illinois Environmental Protection Agency (IEPA) filed proposed amendments to the *Illinois Pollution Control Board Rules and Regulations, Chapter 2: Air Pollution, Part IV: Episodes* (PCB R72-6). These proposed air pollution episode regulations were modified on May 19, 1975, and Dec. 15, 1975. On April 8, 1976, the Illinois Pollution Control Board (PCB) adopted the IEPA's "...Dec. 15, 1975, proposal for amendments to the Episode Regulations as these amendments relate to photochemical oxidants, except for certain minor changes" [Ref. 1].*

This report describes the procedures used to conduct, and the results of, a cost-effectiveness study of the ozone** episode control actions adopted in the April 8, 1976, PCB ruling (PCB R75-4). There are four episode stages that can be declared at specified ozone levels: (1) advisory, for ozone levels of 0.07 ppm; (2) yellow alert, 0.17 ppm; (3) red alert, 0.30 ppm; and (4) emergency, 0.50 ppm. No control actions are taken during advisories.

For each of the 22 control actions [Rule 407(b) of the amendments adopted by the PCB] that can be implemented during ozone yellow alerts, red alerts, and emergencies, the study estimates (1) the "real" costs, as defined in Chapter 2, and (2) the hydrocarbon and nitrogen oxide emission reductions that are likely to result (i.e., the effectiveness). The 22 actions, given in Table 1.1, have been numbered and listed in Table 1.2. The actions are also grouped to reflect the various episode stages and the estimated costs and emission reductions of an advisory, yellow alert, red alert, and emergency are calculated. The annual expected cost and emission reductions of the ozone episode control program are also estimated.

The study area for the analysis is the Chicago Standard Metropolitan Statistical Area (SMSA), consisting of Cook, DuPage, Kane, Lake, McHenry, and Will counties. For two reasons it is assumed that the episode actions are applied throughout the study area: (1) the SMSA is an urban economic unit, and (2) ozone is a regional and not a localized problem. The analysis is conducted for 1974, the latest year for which much of the data is available; information not available for 1974 is adjusted to reflect 1974 levels based

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*References are listed in Sec. 1.6.

**In this report ozone is considered to be synonymous with oxidants.

Table 1.1. Required Emission Reduction Actions Adopted from the Illinois Ozone Episode Regulation

	YELLOW ALERT	RED ALERT	EMERGENCY
AIR POLLUTION CONTROL AGENCIES	Agencies coordinate activities; monitor air quality instruments; evaluate atmospheric conditions and contaminant emissions data; notify public, governmental agenciea, and facilities required to make preparations or take major emission reducing actions.	Agencies coordinate activities; monitor air quality instruments; evaluate atmospheric conditions and contaminant emissions data; notify public, governmental agencies, and facilities required to make preparations or take major emission reducing actions.	Agencies coordinate activities; monitor air quality inatrumenta; evaluate atmospheric conditions and contaminant emiasions data; notify public, governmental agencies, and facilities required to make preparations or take major emission reducing actions.
VEHICLES, PARKING LOTS, ROAD REPAIRS	Public requeated to avoid the unnecesaary use of automobiles.	Public requested to avoid the unnecessary use of automobiles. Fleet vehicles[a] shall not be dispatched on *the first day*, nor operated on *the second and subaequent days*, in or into the Red Alert area. (Does not apply to vehicles being used for mass transit; grocery, pharmaceutical and essential fuel delivery; emergency medical services; and comparable purposes designated by the Agency.[b]) Parking lots for more than 200 vehicles shall *warn uaers on the first day* and *close on the second and subsequent days* of the Alert. (Does not apply to portions of lots serving—or entire lots predominantly serving—residences; grocery stores; medical facilities; rail, bus and air transportation terminals; employees of the lot's tenants or owner; and comparable facilities and persons as designated by the Agency.) Road repair and maintenance not necessary for immediate safety and which, if suspended, will expedite the flow of vehicular traffic ia prohibited.	Motor vehicle operation in or into the area affected by the Emergency is prohibited except for esaential uses auch as police, fire, and health servicea, and comparable usea designated by the Illinois Emergency Highway Traffic Regulation Plan. All aircraft flights leaving the area of the Emergency are forbidden except for reasons of public health or safety.
MANUFACTURING AND OTHER FACILITIES HAVING PROCESS EMISSION SOURCES	Facilities review operations and Action Plana, inspect emission control devices, determine areas of delayable operationa; and from such ateps revise operations so as to cause greatest feasible reduction in emisaiona of organic material (hydrocarbons) and of nitrogen oxidea short of adversely affecting normal production.	Facilities emitting organic material (hydrocarbons) or nitrogen oxides in excess of: (1) 100 tona per year or (2) 550 pounda per operating day or (3) the Illinois emisaion standards shall curtail such emissions to the greatest extent possible (short of causing injury to persons or severe damage to equipment).	All operations curtailed to the greatest extent possible short of causing injury to persons or severe damage to equipment.
ELECTRIC POWER GENERATORS AND USERS	Electric power generating atations burning fossil fuels requested to reduce emissions in and into the affected area to the greatest extent practicable by adjusting operationa system wide or by any other meana approved by the Agency. Public requested to avoid unnecessary uae of electricity.	Electric power generating stations burning fossil fuels required to take all Yellow Alert actions and in addition discontinue power generation for economy sales and service to interruptable customers, and maximize purchase of available power.	Electric power generating stations burning fossil fuel continue Yellow Alert and Red Alert actions and, in addition, effect the maximum feasible reduction of emissions by: Reducing voltage 2.5% syatem wide, purchase all available emergency power, and requesting large customers (500 kW) to reduce their electric demand, or by any other means approved by the Agency. Unnecessary use of electricity, such as for decorative or advertising purposes, is prohibited.
OFFICES, BUILDINGS, AND OTHER COMMERCIAL AND SERVICE OPERATIONS	Public requested to limit apace heating to 65°F; air conditioning to 80°F.	Public, industrial and commercial space heating limited to 65°F, air conditioning to 80°F except for hospitals and and for other buildings approved by the Agency. Governmental agencies except those needed to administer essential programs close. Schools close except elementary schools, which close at the end of the normal school day and do not reopen until the Alert is terminated. The loading of more than 250 gallons of volatile organic material[c] into any stationary tank, railroad tank car, tank truck or tank trailer is prohibited except where an integral part of an industrial operation allowed during Red Alert.	All facilities or activities listed below immediately cease operations: mining and quarrying; contract construction work; wholesale trade establishments; retail trade stores except those dealing primarily in the sale of food or pharmaceuticals; real estate agencies, insurance offices and similar business; laundries; cleaners and dryers; beauty and barber shops; photographic studios; amusement and recreational service establishments such as motion picture theaters; automobile repair and automobile service garages; advertising offices; consumer credit reporting, adjustment and collection agencies; printing and duplicating services; rental agencies; and commercial testing laboratories. All Red Alert closings, and heating, cooling, and organic material loading restrictions, remain in effect.
REFUSE BURNERS	Governmental or commercial installations established primarily for the burning of refuse shall postpone delayable incinerations; all other incineration and all open burning prohibited.	All open burning and all incineration prohibited.	All open burning and all incineration prohibited.

SOURCE: Illinois Pollution Control Board Rules and Regulations, Chapter 2: Air Pollution, Part IV: Episodes, Rule 407(b).

[a] Any one of three or more vehicles operated for the transportation of persons or property in the furtherance of commerical or industrial enterprises, for hire or not for hire.

[b] Agency: Illinois Environmental Protection Agency.

[c] Volatile organic material: any organic material which has a vapor pressure of at least 2.5 lb/in^2 absolute (psia) at 70°F.

Table 1.2. Control Actions for Ozone Episodes

Action No.	Description
1	Public requested to avoid the unnecessary use of automobiles.
2	Facilities[a] review operations and Action Plans, inspect emission control devices, determine areas of delayable operations; and from such steps revise operations so as to cause greatest feasible reduction in emissions of organic material (hydrocarbons) and of nitrogen oxides short of adversely affecting normal production.
3	Electric power generating stations burning fossil fuels requested to reduce emissions in and into the affected area to the greatest extent practicable by adjusting operations system wide or by any other means approved by the Agency.[b]
4	Public requested to avoid unnecessary use of electricity.
5	Public requested to limit space heating to 65° F; air conditioning to 80° F.
6	Governmental or commercial installations established primarily for the burning of refuse shall postpone delayable incinerations; all other incineration and all open burning prohibited.
7	Fleet vehicles[c] shall not be dispatched on *the first day*, nor operated on *the second and subsequent days*, in or into the Red Alert area. (Does not apply to vehicles being used for mass transit; grocery, pharmaceutical and essential fuel delivery; emergency medical services; and comparable purposes designated by the Agency.)
8	Parking lots for more than 200 vehicles shall *warn users on the first day* and *close on the second and subsequent days* of the Alert. (Does not apply to portions of lots serving — or entire lots predominantly serving — residences; grocery stores; medical facilities; rail, bus and air transportation terminals; employees of the lot's tenants or owner; and comparable facilities and persons as designated by the Agency.)
9	Road repair and maintenance not necessary for immediate safety and which, if suspended, will expedite the flow of vehicular traffic is prohibited.
10	Facilities emitting organic material (hydrocarbons) or nitrogen oxides in excess of: (1) 100 tons per year or (2) 550 pounds per operating day or (3) the Illinois emission standards shall curtail such emissions to the greatest extent possible (short of causing injury to persons or severe damage to equipment).
11	Electric power generating stations burning fossil fuels required to take all Yellow Alert Actions and in addition discontinue power generation for economy sales and service to interruptable customers, and maximize purchase of available power.
12	Unnecessary use of electricity, such as for decorative or advertising purposes, is prohibited.
13	Public, industrial and commercial space heating limited to 65° F, air conditioning to 80° F except for hospitals and for other buildings approved by the Agency.
14	Governmental agencies except those needed to administer essential programs close.
15	Schools close except elementary schools, which close at the end of the normal school day and do not reopen until the Alert is terminated.
16	The loading of more than 250 gallons of volatile organic material[d] into any stationary tank, railroad tank car, tank truck, or tank trailer is prohibited except where an integral part of an industrial operation allowed during Red Alert.
17	All open burning and all incineration prohibited.
18	Motor vehicle operation in or into the area affected by the Emergency is prohibited except for essential uses such as police, fire, and health services, and comparable uses designed by the Illinois Emergency Highway Traffic Regulation Plan.
19	All aircraft flights leaving the area of the Emergency are forbidden except for reasons of public health or safety.
20	All operations[a] curtailed to the greatest extent possible short of causing injury to persons or severe damage to equipment.
21	Electric power generating stations burning fossil fuels continue Yellow Alert and Red Alert actions and, in addition, effect the maximum feasible reduction of emissions by reducing voltage 2.5% system wide, purchase all available emergency power, and requesting large customers (500 kW) to reduce their electric demand, or by any other means approved by the Agency.
22	All facilities or activities listed below immediately cease operations: mining and quarrying; contract construction work; wholesale trade establishments; retail trade stores except those dealing primarily in the sale of food or pharmaceuticals; real estate agencies, insurance offices and similar businesses; laundries; cleaners and dryers; beauty and barber shops; photographic studios; amusement and recreational service establishments such as motion picture theaters; automobile repair and automobile service garages; advertising offices; consumer credit reporting, adjustment and collection agencies; printing and duplicating services; rental agencies; and commercial testing laboratories.

SOURCE: Illinois Pollution Control Board Rules and Regulations, Chapter 2: Air Pollution, Part IV: Episodes, Rule 407(b).

[a]Manufacturing and other facilities having process emission sources.

[b]Agency: Illinois Environmental Protection Agency.

[c]Any nne of three or more vehicles ooerated for the transportation of persons or property in the furtherance of commercial or industrial enterprises, for hire or not for hire.

[d]Volatile organic material: any organic material which has a vapor pressure of at least 2.5 lb/in^2 absolute (psia) at 70°F.

on changes in population, employment, income, and other pertinent variables for each control action. All costs are expressed in constant 1974 dollars: dollar figures are adjusted to the 1974 price level using consumer price index figures provided in Table A.6.

Many of the control actions are interdependent, which poses certain problems concerning the appropriate allocation of costs or emission reductions to each interdependent action. Furthermore, the simultaneous impact of interrelated actions may be significantly different than the sum of the impacts of each action considered separately. Therefore, the sums of the costs and emission reductions reported for each individual action within an episode stage do not necessarily equal the cost and emission reductions of the episode stage. However, an attempt is made to identify important interactions and the costs and effects of each action are estimated in such a way as to simplify the procedure for estimating the costs and effects of each episode stage. Thus, simple comparisons of the cost and effects of any two actions can be misleading and summing the impacts of any group of actions may not give a reasonable estimate of the combined effects.

1.1 RELATIONSHIP OF THE STUDY TO PUBLIC ACT 79-790

The cost-effectiveness study described in this document addresses the requirements of Public Act 79-790 [Ref. 2] to the greatest extent possible, given certain important theoretical limitations. It contains no explicit estimate of the benefits of the regulation, but this omission is intentional. The physical relationship between reductions of precursors of photochemical oxidants and changes in ozone levels is not known. Therefore, the marginal effects of episode control actions on ozone levels cannot be determined. Since the primary benefits of the episode control strategies would be derived from reductions in ozone levels, it follows that marginal benefits cannot be estimated.

However, the IIEQ and others have published a number of reports on the deleterious health effects of ozone [Refs. 3 and 4]. These studies, along with reviews of the literature, have been discussed in testimony before the Pollution Control Board, which is a matter of record. Inasmuch as additional refinement would require primary research beyond the scope of this report, this study, along with the testimony presented before the Board, provides as

comprehensive a review of the costs and potential benefits of the proposed ozone episode regulation as is feasible at this time. In doing so, it should satisfy the provisions of PA 79-790.

Another deviation of the study, relative to the requirements of PA 79-790, is that the cost burdens to various sectors of the economy -- including the enforcement and administrative costs of the regulation -- have not been estimated. Many of these distributional costs, though, are implied from the results presented.

1.2 SIMPLIFYING ASSUMPTIONS

Because of the complexity of the ozone episode regulation and the limited resources available for conducting this study, a number of simplifying assumptions are necessary to make the analysis feasible. These are:

- The day of the week that an episode is called is not explicitly considered. It is assumed that episodes occur on weekdays. (The analyses on the prohibition of municipal waste incineration and the closing of schools represent exceptions to this assumption.)
- The time of day that an episode is called is not explicitly considered. It is assumed that episodes begin at the start of the work day. (The analyses of curtailing fleet vehicle operations and airport operations represent exceptions to this assumption.)
- The expected responses to each action are assumed to occur. For example, if compliance is mandatory, full compliance is assumed.

Specific assumptions used to estimate the cost and emission reduction effects of each control action are discussed in later sections of the report.

1.3 INTERPRETATION OF THE RESULTS

It is extremely difficult to assess the accuracy of an analysis of this type. The authors feel that the results provide excellent order of magnitude estimates. This means that if a cost estimate is $5 million, then the actual cost is more like $5 million than it is like either $50 million or $0.5 million.

Although this range is rather large, it should be emphasized that the estimates provided in this document are the best estimates possible given the

available information and resources. In many cases the results are quite accurate. However, it would be inappropriate to claim that the results in general are better than order of magnitude estimates without justifying the claim.

Although the absolute cost and effectiveness estimates are subject to large errors, the relative cost and effectiveness estimates are usually more accurate. Therefore, the identification of the best and worst provisions of the regulation are most likely correct, particularly if the ranking is not very sensitive to the assumptions used. To help readers make judgments on the advantages or disadvantages of each control action, sensitivity analyses are provided.

Sensitivity analyses are conducted when an estimate is based on little or no information. This should be distinguished from sensitivity analyses on the methods used or the data that are available; in general, these types of analyses are not done.

Closely related to the accuracy of the results is the number of significant figures used to report the results. In this report all final results are expressed to three significant figures. This is equivalent to slide rule accuracy, which is more than sufficient for this type of study.

Because results are only presented to three significant figures, readers may find slight discrepancies between the figures reported and their own calculations. For example, in the summary tables the total cost may not exactly equal the sum of the cost components provided in the table. These differences, however, do not affect the accuracy of the analysis.

1.4 NOTATION

The descriptions of the analytical procedures used to estimate the costs and emission effects of each control action and episode stage include discussions of the general mathematical formulations used to obtain the estimates. These mathematical relationships can be used to recalculate the costs or effectiveness of an action if new or improved information becomes available, and can also be used to test the sensitivity of the results to various parameter changes.

Because of the number of actions analyzed, it was impossible, without using overly cumbersome notation, to provide a uniquely defined set of notations. Therefore, the same symbol may have different definitions when used in different chapters (i.e., for different control actions). But for any given action the symbols are uniquely defined. For this reason, all symbols are redefined as appropriate in the text.

To simplify the understanding of the mathmatical relationships, a number of conventions are followed pertaining to notation; these conventions are given below:

$n \equiv$ the length of the episode stage in days

$C \equiv$ a cost

$R_1 \equiv$ the reduction in hydrocarbon emissions

$R_2 \equiv$ the reduction in nitrogen oxides emissions

$W \equiv$ a wage rate

$N \equiv$ the number of establishments, persons, or groups affected by an action

$r \equiv$ the cost of capital

$t \equiv$ time

$V \equiv$ traffic volumes

$E \equiv$ emission factor

$S \equiv$ vehicle speed

$\alpha, \beta, .., \omega \equiv$ variables for which no data are available

1.5 ORGANIZATION OF REPORT

The general concepts and approaches used to estimate costs and emission reductions are discussed in Chapter 2. Chapters 3-24 present the estimated costs and emission reductions for each of the 22 control actions and describe the specific methods and data used to generate the estimates. To aid readers interested in rapidly locating particular information, the discussion of costs precedes that of emission effects for each control action, and a summary result table is provided at the beginning of each chapter.

Chapter 25 presents: (1) the cost and emission reduction effects for each episode stage; (2) the annual cost and emission reduction effects in the Chicago SMSA and Illinois; (3) a comparison of the efficiencies of each control action and episode stage; (4) the distributional effects of the regula-

tion including price and tax implications; (5) a comparison of the recently adopted amendments (R75-4) with the old regulation (R72-6); and (6) a discussion of the overall results of the study.

The main text is followed by appendices that provide additional information and discuss specific estimating procedures that are pertinent to a number of strategies.

1.6 REFERENCES

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2. *Institute for Environmental Quality -- Economic Impact Study*, Public Act 79-790, Senate Bill 805 (Sept. 1975).

3. The Environmental Health Resource Center, *Health Effects and Recommended Alert and Warning System for Ozone*, IIEQ Report 75-17 (July 1975).

4. *The Health Implications of Photochemical Oxidant Air Pollution to Your Community*, U.S. Environmental Protection Agency (Aug. 1976).

2 CONCEPTS AND METHODOLOGIES USED IN THE ANALYSIS

2.1 ECONOMIC ANALYSIS

Government regulation of the production, sale, purchase, or consumption of goods and services is an intervention in the functioning of markets. Regulations can affect the welfare of individuals by changing the benefits they receive from goods and services consumed or the remuneration they receive for services or factors of production supplied to the economy. In an economy with well-functioning markets, regulations can only reduce the general welfare by limiting individuals' abilities to maximize their satisfaction from goods and services consumed and supplied. If, on the other hand, there are market failures [Ref. 1]* the interposition of government regulation may increase society's general welfare. However, as demonstrated by Lipsey and Lancaster [Ref. 9], no a priori assurance can be given that this will be the case.

How does the concept of market failure and the appropriateness of government regulation relate to Illinois' air pollution episode control plan for ozone? Consider air pollution in general; a firm that generates air pollutants while manufacturing a marketable product does not pay for the damage to human health, vegetation, property, etc., caused by the pollutants. That is, the costs to society of polluting the atmosphere are external** to the production of goods and services, and thus the total social cost of production is not reflected in the competitive market prices of the firm's product. This is one form of a market failure, and a case in which the interposition of a government regulation could improve society's general welfare.

A logical question would seem to be: If individuals are damaged by air pollution, why don't they attempt to purchase clean air through the marketplace? The answer to this question involves the concept of a "public good" [Ref. 11]. A public good has two qualities that a private good does not: indivisibility and nonexcludability. Indivisibility requires that no one's satisfaction from the possible consumption of a good be diminished

*References are listed in Sec. 2.3.

**Impacts such as those of air pollution which are disregarded when market transactions take place are referred to as "externalities" by economists.

by the satisfaction that others gain in consuming the good. Nonexcludability means that it is usually not possible for anyone to appropriate the good for personal use. Clearly, ambient air quality has these properties, and is therefore a public good.

Because ambient air quality is a public good, an individual's purchase of cleaner air would also benefit all area residents. However, the costs of obtaining significant improvements in air quality are high -- beyond the financial capability of most individuals -- and since everyone in an area would benefit from a purchase of clean air, even if they did not help pay for it, there would be a tendency to "let the other guy do the job," a tendency which usually results in a job not getting done. This is known as the "free rider" problem in economics.

The dilemma associated with purchasing cleaner air is that while everyone would like it, no one individual or group wants to pay the entire cost. An obvious solution is to have area residents jointly decide how much pollution abatement they wish to buy at a given price, and how the costs should be apportioned among themselves. In Illinois, the Pollution Control Board is empowered to speak for the state's citizens on most matters of pollution abatement and cost apportionment.

Like an individual's decision as to how much of a private good to purchase, the public's decision concerning the amount of a public good to acquire should be based on the costs and benefits of the various possible purchases available. For example, if the costs of the ozone portion of the episode regulations are less than the benefits, then the citizenry may wish to purchase the improved air quality realized by the enactment and enforcement of the regulation. On the other hand, if the costs exceed the benefits, the citizenry may desire to forego purchasing the regulation in its present form.*

The purpose of this study is to help the citizens of Illinois, through the state's Pollution Control Board, decide whether they wish to purchase all or part of the amendments to the ozone portion of the episode control regulation (R75-4). Both the costs of implementing the regulation and the expected reductions in emissions of nitrogen oxides and hydrocarbons are estimated.

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*Theoretically the optimal regulation restricts emissions to the point where marginal benefits equal marginal costs. At this point net benefits (benefits minus costs) will be maximized.

The economic analysis follows Harberger's three basic postulates [Ref. 8]:

1. The competitive demand price for a given unit measures the value of that unit to the demander;
2. The competitive supply price for a given unit measures the value of that unit to the supplier; and
3. When evaluating costs of a given action, the costs accruing to each member of the group (state) are added together without regard to the individual(s) to whom they accrue.

The third postulate implies that the apportionment of costs is not relevant for establishing the economic appropriateness of an action. Apportionment is argued to be irrevelant because a redistribution of income *could* be undertaken in order to benefit everyone when aggregate benefits exceed aggregate costs. However, the distribution of the economic burdens imposed by a regulation is relevant to the social and political appropriateness of the regulation, in view of the fact that redistributions are seldom actually made. The main focus of this study is on estimating the aggregate economic cost of the ozone episode regulations.

In this study the definition of the cost of a regulation proposed by Cohen et al. is used [Ref. 5]:

> For policy evaluation it is imperative to answer the question: What are the *real* costs and benefits to society if the policy is imposed? Real costs are imposed on the society if: (1) the policy requires a reallocation of factors of production (e.g., labor, capital) and resources; or (2) factors or resources that would render services without the policy become obsolete and other factors replace them. These are costs since society has to forego resources that otherwise would be used for investment or consumption. It is important not to confuse income redistribution with either costs or benefits unless the redistribution itself generates costs or benefits.

The last point on income redistribution is another version of Harberger's third postulate, and is discussed by Peskin and Seskin [Ref. 10] when they make the distinction between allocative (e.g., real) and distributional (e.g., pecuniary) effects. Their definition, presented below, also applies if "costs" are substituted for "benefits," and "decreases" for "increases," and vice versa.

> Allocative benefits refer to those effects of a project which are characterized by increases in consumer satisfaction or decreases in the amount of resources required to produce goods and services. Distributional effects, on the other hand, refer

> to changes in some people's well-being at the expense of the well-being of others. It is generally accepted that in a cost-benefit analysis, the allocative benefits should be valued whenever possible, while the strictly distributional effects should be omitted from any valuation.

An example of a possible distributional effect of the episode regulation would be the consumer who purchases a good in Store A, which is not in the area affected by the episode, rather than in Store B, which is closed as a result of an alert. If all other things are equal, there would be no economic cost of this switch since Store B's loss is compensated for by Store A's gain. Most substitutions of this kind are difficult to forecast without a great deal of data on the type of economic disruptions caused by episode controls; since this type of data does not exist, this study does not attempt to identify substitution effects.

In addition to the basic concepts just described, an assumption is made that greatly simplifies the entire economic analysis without significantly affecting its accuracy. The assumption is that adjustments are made by individuals and groups that result in little or no loss of production or consumption because of an ozone episode. The basis for this assumption is that the expected duration of an episode is less than five days and the expected frequency of calling a red alert, or an emergency, is less than once a year [Ref. 4]. This study therefore assumes that short, infrequent interruptions in normal business operations can be compensated for with little or no loss in production or consumption in most sectors of the economy.

The expenditures made for adjustments to avoid production or consumption losses are real economic costs and are included in the cost estimates of all relevant actions. Other costs include expenditures caused by the regulation or losses in consumer satisfaction. Psychic or inconvenience costs are real and should be considered; the scope of this project does not permit quantification of these costs, however, when appropriate, they are qualitatively discussed.

The methods used to estimate adjustment and other costs of the episode actions are discussed in the remainder of this section.

Adjustment Cost to Avoid Production Losses (Inventory and Overtime Cost)

The provisions of the regulation for manufacturers, utilities, incinerator operations etc., directly affect these firms' production processes and indirectly affect their employees. If the product being made can be inventoried, then an industry can plan for the occurrence of an episode and increase its inventories. Increases in inventories, however, do not necessarily have to be made by the producer of goods. Customers may wish to hold additional inventories if they feel a disruption in supply would adversely affect their operations. Therefore, care should be taken to avoid double counting, i.e., both producer and customer need not increase inventories.

Increased inventory costs are estimated as:

$$C_{1j} = (d \cdot U_j/365)\ [(1 + i)^{\hat{T}} - 1] + SR_j \qquad (2.1)$$

where:

C_{1j} ≡ the increased inventory costs of industry j,
d ≡ lost production days due to the episode,
U_j ≡ the annual value of production in industry j,
i ≡ the daily cost of capital,
$\hat{T}$ ≡ the number of days the extra inventory is held, and
SR_j ≡ the storage and retrieval costs for industry j.

Frequently debated is the appropriate value of the cost of capital, i.e., the social discount rate. [For example, Refs. 2, 7, 12, and 13]. Since the State of Illinois is an open economy, the social discount rate in Illinois is equal to that in the United States. Seagraves argues that the annual rate is 8-13% [Ref. 13]. In this study an annual rate, r, of 10% is used; the equivalent value of i is 0.00026.*

When estimating the cost of increasing inventories, it is assumed that no capital costs are needed to increase storage capacity. Since we are analyzing entire industries rather than specific firms, and the amount of increased storage is small because the frequency and duration of episodes are expected to be small, this assumption is reasonable. The inventory cost can be interpreted as the interest cost of holding the extra inventories. The amount of the extra inventory held is assumed to be equal to the expected

*$(1 + 0.10)^1 = (1 + 0.00026)^{365}$

loss in production if an episode occurs (i.e., $d \cdot U/365$). The number of lost production days, d, is greater than or equal to the expected duration of an episode; it would equal the episode duration if there is no lost time to start up operations after the episode. It is further assumed that the increased inventories are held only for the period of time that an episode is likely to be called. Since an ozone episode would most likely occur in the warmer months of the year, $\hat{T}$ may be set equal to 182 days or half a year. (The maximum value of $\hat{T}$ is 365 days since we are estimating annual costs.)

If an industry's product cannot be stored or if there is no excess storage capacity, then the lost production time caused by an episode might be made up by using overtime labor. The cost of this adjustment is:

$$C_{2j} = (W_{oj} - W_{nj}) \cdot M \tag{2.2}$$

where:

C_{2j} ≡ the cost of overtime in industry j,
W_{oj} ≡ the overtime hourly wage rate in industry j,
W_{nj} ≡ the normal hourly wage rate in industry j, and
M ≡ the number of man-hours lost due to an episode.

Using Eqs. 2.1 and 2.2 and summing over the affected industries yields an estimate of the adjustment costs that must be borne by the industrial sector to avoid losses in production. Symbolically, this summation is:

$$C_2 = \sum_{j \varepsilon I} C_{1j} + \sum_{j \varepsilon O} C_{2j} \tag{2.3}$$

where:

C_2 ≡ the total adjustment costs of industry,
I ≡ the industries using the inventory adjustment, and
O ≡ the industries using the overtime adjustment.

It is possible that a given firm in an industry cannot adjust in either of these two ways. This could occur if the firm is operating at full capacity (24 hours a day, 7 days a week) and has no excess storage capacity. Under this extreme circumstance this firm would most likely not be able to recover its lost production. However, this situation would have to be widespread throughout an entire industry before this lost production would represent a cost of the regulation since the production could shift to another firm in the industry. Therefore, for most industries we assume that either

one or both of the two adjustments is feasible and there is no loss of production. Exceptions to this assumption are identified in the empirical section of this report.

The costs of these adjustments represent costs of the regulation; however, they are not necessarily distributed evenly between employers and employees (or indirectly to consumers and stockholders). When the inventory option is used employers must pay the additional costs, some of which may be passed on to consumers in the form of higher prices or to stockholders in the form of reduced dividends; this option would have little or no effect on aggregate wages paid to employees. On the other hand, overtime costs may result in increased aggregate wages with the costs again being initially borne by the employers. However, the ultimate distributional effects are unclear.

It should be noted that if workers' contracts require an employer to pay wages for the days lost due to an episode, these payments are income redistributions and not costs of the regulation.

Adjustment Cost to Avoid Lost Consumption (Delay Cost)

Productivity within the retail and service sectors is often demand-determined. For example, a sale cannot be made unless a customer is present and/or willing to make a purchase. Therefore, the adjustments made for these sectors are most likely made by the consumer, and the simplest adjustment is to delay the purchase of a good or service. The cost of delayed consumption can be interpreted as a loss of satisfaction to the consumer. The general cost equation for calculating the cost of delays is:

$$C_{3k} = U_k \cdot [1 - 1/(1 + i)^T] \tag{2.4}$$

where:

$C_{3k} \equiv$ the costs of delaying the purchase of good k,
$U_k \equiv$ the value of good k,
$i \equiv$ the daily cost of capital, and
$T \equiv$ the number of days of the delay.

To calculate the costs of delayed consumption, the length of the delay, T, must be specified. Everyone who delayed their purchases because of an episode would not be expected to make the purchase immediately after the episode is over, nor would many consumers be expected to delay their purchases

for long periods of time. In order to estimate the importance of this parameter, minimum (T_m) and maximum (T_M) delay periods are defined and a uniform distribution of delays between these extremes is assumed, which results in delay costs of:

$$C_{3k} = U_k \cdot \left\{ 1 - \left[1/(1 + T_M - T_m) \right] \left[\sum_{T=T_m}^{T_M} 1/(1+i)^T \right] \right\} \qquad (2.5)$$

Table A.7 in Appendix A provides values of C_{3k} with $U_k = 1$ for various combinations of T_m and T_M. These data are referred to in this document as "delay cost factors" or just "delay factors." In the empirical analysis specific values of T_m and T_M are assumed and the appropriate delay factors from Table A.7 are used.

The delay costs calculated using Eq. 2.5 will tend to be overestimates because the equation assumes that consumption and purchases occur at the same time and that there is no value for substitutes of the delayed purchase. Many items, however, are purchased and stored before they are used. If the item is stored after it is purchased for a length of time greater than the length of the episode period, it is possible that its consumption will not be delayed and thus there will be no delay costs. An example of this situation would be a food product stored at home for future consumption. If the product can be purchased after the episode without delaying its consumption, then there would be no delay costs.* On the other hand, if the food product is planned to be used for a meal on the day it is purchased, then a delay in its purchase would require the use of a substitute food product already on hand. In this case there would be a delay cost; however, Eq. 2.5 does not account for any value that the substitute product may have. This example can be extended to all consumer products by considering use as a form of consumption.

Substitutions of another nature must also be discussed at this point. It is implicitly assumed in the analysis that consumers will purchase the identical bundle of goods with or without an ozone episode. However, it is likely that some purchases will be permanently foregone, or that the same good may be purchased but from a different supplier. Substitutions of this kind

*There may be an inconvenience cost caused by forcing a change in shopping schedules.

are extremely difficult to estimate. Furthermore, it is not known a priori if these substitutes result in aggregate costs which must be assigned to the regulation. However, it can be argued that if such substitutions do occur, then any reduction in consumer satisfaction must be less than or equal to the lost satisfaction incurred from delaying the originally planned purchase. Therefore, the delay cost to consumers represents an upper bound even if substitutes are considered.

For some control actions the cancellation of specific purchases is considered explicitly. For this situation the full value of the canceled purchase is the cost assigned to the regulation. Because substitute purchases are likely and not taken into account, the cancellation cost estimates will be high.

Notification Cost

Two methods of notifying the public, employees, government agencies, and customers of an episode and the requested or required actions are assumed in the analysis: radio and television announcements when many individuals need to be notified and telephone calls when relatively few persons need to be contacted. Furthermore, the telephone is assumed used if personal contact between two parties is necessary to carry out the intent of the regulation or adjust to it.

The cost of electronic media announcements is the value of the air time used, i.e., the resource used, and is estimated as:

$$C_{4i} = N_i \cdot H_i \cdot L_i \cdot U_i \tag{2.6}$$

where:

C_{4i} ≡ the cost of announcements through medium i;
i ≡ type of medium: 1 = radio, 2 = television;
N_i ≡ the number of stations of medium i;
H_i ≡ the average number of announcements made per station;
L_i ≡ the length of the announcements (minutes); and
U_i ≡ the value of a minute of air time in medium i.

The total cost of radio and television announcements is the sum of C_{41} and C_{42}. These costs are estimated in Appendix D.

The cost of notifying people by telephone is estimated using the following general equation:

$$\overline{C}_4 = N\cdot(T + W\cdot L + \overline{W}\cdot L) \qquad (2.7)$$

where:

$\overline{C}_4$ ≡ the telephone notification cost,

N ≡ the number of telephone calls made,

T ≡ cost of a telephone call,

W ≡ the wage rate or value of time of the person making the telephone call,

$\overline{W}$ ≡ the wage rate or value of time of the person receiving the telephone call, and

L ≡ the average length of a telephone call (units must be consistent with W and $\overline{W}$).

This estimating procedure results in a conservative (high) cost estimate since it fully allocates all of the resource costs associated with making these telephone calls to the cost of the regulation.

Cost of Shutting Down and Starting Operations

The cost of closing down a firm during an episode and starting it up again after the episode may be as simple as locking the doors to the plant or may require a significant amount of labor and/or materials to ensure that equipment is not damaged, raw materials are properly stored, and/or the production process is properly terminated or begun. The general equation for estimating these costs is:

$$C_{5j} = N_j\cdot[(M_j\cdot W_j + R_j) + (\overline{M}_j\cdot W_j + \overline{R}_j)] \qquad (2.8)$$

where:

C_{5j} ≡ the cost of shutting down and starting up equipment in industry j,

N_j ≡ the number of facilities in industry j that are shut down during an episode,

M_j ≡ the man-months of labor required to shut down a facility in industry j,

$\overline{M}_j$ ≡ the man-months of labor required to restart a facility in industry j,

W_j ≡ the monthly wage rate of skilled labor in industry j,

R_j ≡ the value of the resources (fuel, raw product, etc.) required to shut down a facility in industry j, and

$\overline{R}_j$ ≡ the value of resources required to restart a facility in industry j.

The costs of shut-downs and start-ups are calculated separately for each industry affected during a given level of an episode (e.g., manufacturing, office-commercial, and government). Total shut-down and start-up costs are equal to:

$$C_5 = \sum_j C_{5j} \tag{2.9}$$

Cost of Rescheduling Operations

When economic activity is interrupted by an episode, production and sales may be rescheduled so that the monthly or yearly demand can be met. Rescheduling may involve planning, to bring additional resources (overtime or additional labor) into the production process, or simply altering vacation time for employees. The assumption is made that rescheduling can be accomplished without additional capital or non-labor resources; rescheduling does require management personnel's time.

The formula used to calculate the cost of rescheduling is:

$$C_{6j} = \overline{N}_j \cdot M_j \cdot \hat{W}_j \tag{2.10}$$

where:

C_{6j} ≡ the cost of rescheduling in industry j,

$\overline{N}_j$ ≡ the number of activities in industry j needing rescheduling,

M_j ≡ the man-months of management personnel required to reschedule production or sales in industry j, and

$\hat{W}_j$ ≡ the monthly wage rate of management personnel in industry j.

Total rescheduling costs are:

$$C_6 = \sum_j C_{6j} \tag{2.11}$$

Special (Miscellaneous) Cost

For some actions there are costs that are specific to that action. These include costs of reviewing action plans, inspecting control equipment, spoilage of resources (perishable goods), child care, landfilling solid waste, rerouting travelers, and substituting mass transit for the automobile. In

addition, there may be some savings due to changes in modes of travel or production. The methods used to estimate these costs and savings are described in the appropriate sections on the individual actions.

Summary of Costs Estimated for Each Action

Table 2.1 shows the different cost estimates made for each action. The specific applications of the cost estimation methodologies described in this section, and the data and assumption used to quantify these costs, are presented in Chapters 3-24.

2.2 EMISSION REDUCTION ANALYSIS

Vehicular Emission Sources

Traffic emissions can be affected in two ways by the ozone regulation. Emissions are lowered when vehicle miles traveled are reduced, and a change in the average traffic speed may decrease or increase emission rates. An

Table 2.1. Costs Estimated for Each Action

Episode Action	Inventory	Overtime	Delayed or Foregone Consumption	Radio & TV Notification	Telephone Notification	Shut-Down/ Start-Up	Rescheduling	Special
1	-	-	X	X	X	-	-	-
2	-	-	-	-	X	-	-	X
3	-	-	-	-	X	-	-	X
4	-	-	X	X	-	-	-	X
5	-	-	X	X	-	-	-	X
6	-	-	-	X	X	-	X	X
7	-	X	X	-	X	X	X	-
8	-	-	X	X	X	-	-	X
9	-	-	X	-	X	-	X	-
10	X	X	-	X	X	X	X	X
11	-	-	X	-	X	-	-	X
12	-	-	X	X	-	-	-	X
13	-	-	X	X	-	-	-	X
14	-	-	X	X	-	-	-	-
15	-	-	-	X	-	-	-	X
16	-	X	-	X	-	-	X	-
17	-	X	-	X	X	X	X	X
18	X	X	X	X	X	X	X	X
19	-	-	X	X	X	X	X	X
20	X	X	-	X	X	X	X	X
21	-	-	X	X	X	-	-	X
22	X	X	X	X	X	-	X	-

action may affect emissions in either or both ways. An action affects emission in both ways when partial curtailment reduces congestion, which results in an increased average traffic speed for the remaining vehicles.

Emission reductions due to traffic curtailment are based on the following equation:

$$R_p = \sum_{j=1}^{4} \sum_{i=1}^{9} V_{ij} \cdot f_{ij} \cdot E_{pi}(S_j) \cdot F \qquad (2.12)$$

where:

R_p ≡ vehicle emission reduction of pollutant p due to traffic curtailment (tons/day);

p ≡ pollutant: 1 = hydrocarbons, 2 = nitrogen oxides;

j ≡ traffic segment: 1 = expressway peak, 2 = expressway off-peak, 3 = arterial peak, 4 = arterial off-peak;

i ≡ vehicle class (see Appendix E);

V_{ij} ≡ vehicle miles traveled (Vmt) of vehicles of class i during traffic segment j (miles/day);

f_{ij} ≡ fraction by which V_{ij} is reduced by the action;

$E_{pi}(S_j)$ ≡ emission rate of pollutant p by vehicles in class i at average speed S_j (grams/mile); and

F ≡ a factor that converts grams to tons.

The emission effect due to an average speed change is calculated from the following equation:

$$R_p^* = \sum_{j=1}^{4} \sum_{i=1}^{9} V_{ij}^* \cdot [E_{pi}(S_j) - E_{pi}(S_j^*)] \cdot F \qquad (2.13)$$

where:

R_p^* ≡ change in emissions of pollutant p due to a change in average traffic speed (tons/day);

V_{ij}^* ≡ Vmt of class i vehicles during traffic segment j which experience a speed increase (miles/day);

$E_{pi}(S_j^*)$ ≡ emission rate of pollutant p for vehicles of class i at average speed S_j^* after the action (grams/mile); and

p, j, i, $E_{pi}(S_j)$, and F are defined as in Eq. 2.12.

For the case in which an action affects emissions in both ways, $V_{ij}^* = V_{ij} - V_{ij} \cdot f_{ij}$ and the total change in emissions is $R_p + R_p^*$.

The procedure for estimating the increase of average vehicle speed resulting from traffic curtailment is discussed in Appendix F.

Stationary Emission Sources

Emissions from power plants and incinerators are estimated using (1) operational data supplied by the Commonwealth Edison Co. and the City of Chicago on fuel consumption and waste incineration, and (2) emission factors found in *Compilation of Air Pollution Emission Factors* [Ref. 6]. The resulting emissions are compared to emissions from other sources when the latter are available.

Emissions from manufacturing and other large hydrocarbon and nitrogen oxide sources were obtained for an emission inventory supplied by the IEPA [Ref. 3]. While these data may not be completely accurate, they are the best available for conducting this study. The IEPA's description of the inventory [Ref. 3] emphasizes these points:

> The State's point source emission inventory, complete with field verification, will not be available until mid-summer of this year [1976].* That which is enclosed is the same except that it lacks field verification and it does not include sources emitting less than 25 tons annually of a specific pollutant. The lack of data for the smaller sources should cause few problems since these are not ordinarily covered in episode action plan requirements.

Full details of the data and estimating procedures used are provided in the appropriate empirical sections of this report.

Evaporative Hydrocarbon Emissions

Evaporative hydrocarbon emissions are estimated for the marketing and transportation of gasoline. Reductions of these emissions occur when the loading and unloading of volatile organics are prohibited and when gasoline sales are reduced. Average gasoline sales are reduced whenever vehicular travel is reduced.

The evaporative hydrocarbon emissions are estimated as follows:

$$R_g = Q \cdot E_g \tag{2.14}$$

*As of December 1976 the inventory was not completely verified.

where:

R_g ≡ evaporative hydrocarbon emission reduction (tons/day),
Q ≡ reduced quantity of gasoline loaded, unloaded or sold (gallons/day),
E_g ≡ emission rate of hydrocarbons (tons/gallon). The values of E_g are obtained from Ref. 6.

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3 REQUEST TO AVOID UNNECESSARY USE OF AUTOMOBILES -- ACTION 1

During a yellow alert, the public is asked to avoid unnecessary use of automobiles. Compliance with this action is entirely voluntary and "unnecessary use" is not defined. To estimate the cost and emission reduction effects of Action 1, it is assumed that the public interprets "unnecessary use of the automobile" to include all trips other than those to work, work-related locations, and school. Because the action is voluntary, only a fraction of other automobile trips is assumed to be delayed or canceled. The costs and emission reduction effects of Action 1, summarized in Table 3.1, are based on these assumptions and others discussed below.

3.1 COSTS OF ACTION 1

For Action 1 three types of costs are estimated, those of: (1) notifying the public of the alert, (2) notifying second parties of delayed or canceled trips, and (3) delaying purchases associated with shopping trips. The data, assumptions, and methods used to estimate these costs are discussed below.

Notification Cost

Radio and television announcements are assumed to be used to request that the public avoid unnecessary use of automobiles. The cost of these announcements is estimated to be $6,800 per day, as derived in Appendix D.

Table 3.1. Summary of the Costs and Emission Reduction Effects of Avoiding Unnecessary Driving

Episode Length (days)	Costs ($\$10^3$)				Emission Reductions (tons)	
	Notification		Delay of Purchases	Total		
	Radio, TV	Individual			HC	NO_x
1	6.80	30.4	1.36	38.6	31.0	22.0
2	13.6	60.9	2.73	77.2	62.0	44.0
3	20.4	91.3	4.09	116	92.9	66.0
4	27.2	122	5.46	155	124	88.0
5	34.0	152	6.82	193	155	110

To estimate the cost of notifying passengers not residing with the driver, it is assumed that a two-minute telephone call is necessary for each passenger. The passenger notification cost for an n-day episode is:

$$C = N\cdot(T + 2\cdot W/30)\cdot\rho_1\cdot\rho_2\cdot n \qquad (3.1)$$

where:

$C \equiv$ the passenger notification cost,

$N \equiv$ the total number of passengers involved per day,

$T \equiv$ the cost of a telephone call,

$W \equiv$ the value of an hour's time for the persons making and receiving the telephone call,

$\rho_1 \equiv$ the fraction of passengers not residing with the driver,

$\rho_2 \equiv$ the fraction of persons volunteering to delay or cancel an automobile trip, and

The constant 30 is the number of two-minute periods in an hour.

The number of passengers, N, is estimated from the data provided in Table 3.2; the table is based on information in Ref. 2.* Summing the number of passengers taking shopping, social/recreation, personal business, and other trips provides an estimate of N = 2.283 million persons per day. The cost of a telephone call, T, is assumed to be $0.10 and the value of time, W, is $2.50/hr [Ref. 4]. Substituting these values of N, T, and W into Eq. 3.1 yields:

$$C = 608{,}800\cdot\rho_1\cdot\rho_2\cdot n \qquad (3.2)$$

Table 3.2. Number of Automobile Trips and Passengers

Trip Purpose	Thousands of Trips	Thousands of Passengers
Home	4,527	2,159
Work	1,731	327
Work-Related	512	29
School	108	225
Shopping	1,482	749
Social/Recreational	1,314	1,125
Personal Business	754	354
Other	510	55

*References are listed in Sec. 3.4.

It is reasonable to assume that about half of the passengers reside with the driver. Judging from past yellow alerts, a 10% compliance rate would result in a conservative estimate of ρ_2; the results in Table 3.1 are based on assumed values of $\rho_1 = 0.5$ and $\rho_2 = 0.1$.

Delay of Purchases

Postponement of some automobile trips may also result in the delay of purchases (e.g., shopping trips). The delay cost associated with the postponement of consumption is estimated to be, for an n-day episode:

$$\overline{C} = A \cdot D \cdot F \cdot \rho_2 \cdot n$$

where:

$\overline{C} \equiv$ the cost of delayed purchases,

$A \equiv$ the value of daily purchases in affected industries,

$D \equiv$ the delay cost factor,

$F \equiv$ the fraction of purchases made by persons that use automobiles, and

$\rho_2 \equiv$ the fraction of persons complying with the regulation.

The 2-digit SIC industries that are most likely to be affected by the postponement of automobile trips, and the amount of daily personal income allocated to each industry (see Appendix C), are given in Table 3.3, which

Table 3.3. Two-Digit SIC Industries Affected by Action 1

SIC	Industry	Allocated Daily Personal Income ($\$10^3$)
52	Building Materials and Farm Equipment	569
53	General Merchandise	4,031
54	Food Stores	1,939
55	Automobile Dealers and Service Stations	2,471
56	Apparel and Accessory Stores	1,112
57	Furniture and Home Furnishings Stores	2,708
58	Eating and Drinking Places	2,209
59	Miscellaneous Retail Stores	1,480
72	Personal Services	1,134
79	Amusement and Recreational Services	683
84	Museums and Botanical and Zoological Gardens	87
	TOTAL	18,423

estimates the value of A to be \$18.423 million. To estimate D, a minimum delay of a purchase of one day and a maximum delay of seven days are assumed regardless of the length of the episode. The delay period is assumed to be independent of the length of the episode because Action 1 involves voluntary compliance. From Table A.7 the value of D is $7.8274 \cdot 10^{-4}$.

The total number of persons taking shopping, social/recreational, personal business, and other trips each day is 6.704 million, of which 6.343 million travel by automobile [Ref. 2]. If the average expenditure is assumed to be independent of the mode of travel, then F = 6.343/6.704 = 0.9462. The value of ρ_2 is set equal to 0.1, as it was in estimating the notification cost.

Substituting these values of A, D, F, and ρ_2 into Eq. 3.3 results in the estimated delay-of-purchase cost provided in Table 3.1.

3.2 EMISSION REDUCTION EFFECTS OF ACTION 1

It is assumed that some light truck travel as well as automobile travel will be curtailed since a significant part of light truck travel is for personal business. The action's vehicular source emissions reduction is:

$$R_p = \sum_{j=1}^{4} V_j \cdot f_j \cdot \alpha_j \cdot E_p(S_j)/907{,}184 + \sum_{j=1}^{4} V_j' \cdot g_j \cdot \beta_j \cdot E_p'(S_j)/907{,}184 \qquad (3.4)$$

where:

$R_p \equiv$ emission reduction of pollutant p due to the action (tons/day);

$p \equiv$ pollutant: 1 = hydrocarbons, 2 = nitrogen oxides;

$j \equiv$ traffic segment: 1 = expressway peak, 2 = expressway off-peak, 3 = arterial peak, 4 = arterial off-peak;

$V_j, V_j' \equiv$ passenger auto and light truck Vmt, respectively, in traffic segment j (miles/day);

$f_j, g_j \equiv$ fraction of passenger auto and light truck Vmt, respectively, during traffic segment j which is "unnecessary";

$\alpha_j, \beta_j \equiv$ fraction of "unnecessary" passenger auto and light truck Vmt, respectively, in traffic segment j which is voluntarily curtailed;

$E_p(S_j) \equiv$ passenger auto emission factor for pollutant p at average speed S_j (grams/mile);

$E_p'(S_j) \equiv$ light truck emission factor for pollutant p at average speed S_j (grams/mile); and

The constant (1/907,184) converts grams to tons.

It is estimated that travel for shopping, social/recreational, personal business, and other purposes accounts for 55.9% of the passenger auto Vmt in the SMSA (see Appendix E for the procedure used to estimate this figure). The assumption is made that 10% of the travel in these four categories is actually curtailed during a yellow alert, i.e., $\alpha_j = \beta_j = \rho_2$. Since the traffic in these four categories is estimated to be insignificant during the peak hours (as discussed in Appendix E) only the two off-peak traffic segments experience a Vmt reduction.

Table 3.4 is a compilation of the data needed to evaluate the effectiveness of the action for passenger autos. The estimated emission reductions due to the public curtailing the unnecessary use of passenger autos are calculated from Eq. 3.4 as:

HC reduction = 28.6 tons/day, and

NO_x reduction = 21.9 tons/day.

The estimates of emission reductions due to curtailing light truck travel are based on sketchy data, necessitating many assumptions. However, the number of light truck trips for personal use is only 8.5% of the total

Table 3.4. Data Used to Estimate the Emission Reduction Effects of Action 1

Data Element	Expressway Off-Peak	Arterial Off-Peak
Passenger Auto Vmt (miles/day)[a]	14.746×10^6	42.250×10^6
Fraction of Auto Vmt for Shopping Social/Recreational, Personal, Business, and Other Purposes[b]	0.820	0.818
Fraction of Such Traffic Curtailed[c]	0.10	0.10
HC Emission Factor (grams/mile)[d]	4.36	5.98
NO_x Emission Factor (grams/mile)[e]	4.84	4.06

[a]From Table E.16.

[b]Based on Table E.14.

[c]Assumed value.

[d]From Table E.4.

[e]From Table E.5.

number of light truck trips;* and because the amount of light truck travel is so small relative to passenger auto travel, the effect of curtailing personal use of light trucks is practically insignificant no matter what assumptions are made. The following emission reduction estimates are based on seemingly reasonable assumptions.

Out of the total 1,021,392 light truck trips in the eight-county CATS study area, 86,474 are for personal use [Ref. 3]. Based on CATS data, 91.9% of all internal light truck trips are in the Illinois portion of the eight-county CATS study area and the average trip length for light trucks is calculated at 4.65 miles [Ref. 3]. Assuming that (1) 91.9% of *all* light truck trips in the CATS study area are in the six Illinois counties (data are available only for internal trips), and (2) that all vehicles in the CATS light truck category are under 8,500 lb gross vehicle weight (GVW), the Vmt by trucks under 8,500 lb GVW in the SMSA for personal use are estimated at:

$$\text{Vmt} = 86{,}474 \cdot 0.919 \cdot 4.65 = 369{,}534 \text{ miles/day}$$

If it is assumed that 55.9% of this personal use Vmt is for purposes other than work, work-related, and school (as was the case with passenger autos), then the "unnecessary" light truck Vmt = 369,534 · 0.559 = 206,570 miles/day. Assuming that this travel occurs only during off-peak hours, that it is divided between arterials and expressways as general traffic (25.9% expressway, 74.1% arterial [Ref. 5]), and that 10% will actually be curtailed during an ozone yellow alert, the resulting reductions in emissions from Eq. 3.4, calculated using the emission factors from Tables E.4 and E.5, are:

HC reduction = 0.198 tons/day, and

NO_x reduction = 0.118 tons/day.

Adding the light truck and passenger auto reductions, the vehicular source reductions are estimated as:

$$R_1 = 28.6 + 0.198 = 28.8 \text{ tons HC/day}$$

$$R_2 = 21.9 + 0.118 = 22.0 \text{ tons } NO_x\text{/day}$$

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*As reported in a Chicago Area Transportation Study (CATS) commercial vehicle survey [Ref. 3], 80,464 of a total 1,005,612 internal light truck trips in the eight-county CATS study area ("internal" trips originate and end within the study area) are for personal use. For external light truck trips (those with origin and/or destination outside the CATS study area), 6,010 out of a total 15,780 trips are for personal use. Overall, 8.5% of light truck trips as defined by CATS is for personal use.

Since the traffic reductions occur during the off-peak hours, the traffic remaining on the road is unlikely to experience an increase in speed, and the emission reduction is due entirely to the traffic curtailment.

The total HC emission reduction is the sum of R_1 and the evaporative emission reduction due to reduced average sales of gasoline. The evaporative emission reduction is estimated in Appendix G to be 2.18 tons HC/day. Therefore, the total HC emission reduction is:

$$28.8 + 2.18 = 31.0 \text{ tons/day}$$

The total emission reduction effects for HC and NO_x for episodes of various lengths are summarized in Table 3.1.

3.3 SENSITIVITY ANALYSIS FOR ACTION 1

The results presented in Table 3.1 are based on assumptions about the values of (1) the fraction of passengers not residing with the drivers of trips postponed -- i.e., ρ_1, and (2) the fraction of individuals that will postpone a trip -- i.e., $\rho_2 = \alpha_j = \beta_j$. The effects of these two assumptions on the results presented are quite different. Changes in the value of ρ_1 significantly affect the efficiency of Action 1, as measured by a cost/effectiveness ratio, but have relatively small effects on the action's total cost and no effect on the emission reductions. On the other hand, the changes in value of ρ_2 significantly affect the cost and effectiveness estimates but not the efficiency. To illustrate these points, a number of parametric analyses are presented below in which the values of ρ_1 and ρ_2 are varied between their extremes of 1.0 and 0.0.

Holding ρ_2 constant at 0.1, the cost of a one-day episode varies from \$68,210 to \$7,410 as ρ_1 varies from 1.0 to 0.0. The cost/effectiveness ratio for hydrocarbons ranges from 68.21/31.0 = 2.20 to 13.49/31.0 = 0.435 as ρ_1 varies from 1.0 to 0.1.

If ρ_1 is held constant at 0.5, then the cost of Action 1 varies from \$323,650 to \$6,043 as ρ_2 varies from 1.0 to 0.0. The cost/effectiveness ratio for hydrocarbons ranges from 323.7/309.8 = 1.04 to 37.8/31.0 = 1.22 as ρ_2 varies from 1.0 to 0.1.

The cost/effectiveness ratios for NO_x or a combination of HC and NO_x vary in the same way as the HC cost/effectiveness ratios calculated above.

The effectiveness values of Action 1 for various values of ρ_2 are proportional to the ρ_2 values. Except for the radio and TV notification costs, the costs are also proportional to ρ_2, which explains why the efficiency of Action 1 is relatively insensitive to the assumed value of ρ_2. On the other hand, only the passenger notification costs are affected by the assumed value of ρ_1; thus the efficiency of the action varies with ρ_1.

The values of ρ_1 and ρ_2 used in the analysis are the best estimates of these variables that can be obtained at this time.

3.4 REFERENCES

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2. *Purpose, Mode, Time of Day,* Chicago Area Transportation Study, CATS 372-49 (Nov. 1975).

3. Warnke, J., and D.A. Zavattero, *Motor Truck Freight in the Chicago Region,* Chicago Area Transportation Study (to be published).

4. Zerbe, R.O., and K.G. Croke, *Urban Transportation for the Environment,* Ballinger Publishing Co., Cambridge, Mass. (1975).

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4 REVIEWING ACTION PLANS AND INSPECTING EMISSION CONTROL DEVICES --ACTION 2

During a yellow alert facilities engaged in manufacturing are required to review operations and action plans, inspect emission control devices, and determine areas of delayable operations; and from such steps revise operations so as to cause the greatest feasible reduction in emissions possible without adversely affecting normal production.

Although compliance is required, the nature of the operational revisions is not specified, except that plant operators are told, within the regulation, that normal production need not, and perhaps should not, be altered by compliance. For these reasons, it is assumed that normal operations are not altered as a result of Action 2. A summary of the costs and emission reduction effects of the action is provided in Table 4.1.

Table 4.1. Summary of the Costs and Emission Reduction Effects of Reviewing Action Plans and Inspecting Emission Control Devices

Episode Length (days)	Costs ($\$10^3$)				Emission Reductions (tons)	
	Notification	Plan Review	Device Inspection	Total	HC	NO_x
1	0.125	1.15	3.80	5.08	0	0
2	0.125	1.15	3.80	5.08	0	0
3	0.125	1.15	3.80	5.08	0	0
4	0.125	1.15	3.80	5.08	0	0
5	0.125	1.15	3.80	5.08	0	0

4.1 COSTS OF ACTION 2

The costs of Action 2 include those of notifying each firm of the yellow alert, reviewing action plans, and inspecting control equipment. Because it is assumed that these costs will be incurred only on the first day of an episode, they are not a function of episode length.

Notification Cost

It is assumed that each manufacturing firm that is required to submit an action plan is contacted by telephone by a control agency staff member. Assuming the call lasts two minutes, the notification cost is estimated to be:

$$C = N \cdot (T + W/5040 + \overline{W}/5040) \tag{4.1}$$

where:

$C \equiv$ the notification cost,

$N \equiv$ the number of manufacturing plants requiring an action plan,

$T \equiv$ the cost of a telephone call,

$W \equiv$ the monthly salary of the person making the telephone call,

$\overline{W} \equiv$ the monthly salary of the person receiving the telephone call, and

The constant 5040 is the number of two-minute time periods in a working month (i.e., in 21 eight-hour days).

The episode regulation requires many types of facilities to submit action plans. However, manufacturing firms are most likely to fall into two categories:

- Facilities having fuel combustion emission sources with a total rated heat input greater than 10 million Btu/hr burning coal or fuel oil, and
- Facilities emitting more than 100 tons/yr or 550 lb/operating day of sulfur dioxide, carbon monoxide, nitrogen oxides, particulate matter, organic material, or any other air contaminant designated by the IEPA as harmful to human health [Ref. 2].*

Argonne's 1968 emission inventory for the Chicago SMSA listed 137 fuel combustion sources (excluding power plants) with heat inputs greater than 10 million Btu/hr.** Of these sources, 20 were not manufacturers. If it is assumed that about 20 new manufacturing sources entered this category between 1968 and 1974, then 137 large manufacturing fuel combustion sources are required to submit action plans. A recent emission inventory provided by the Illinois EPA lists 383 facilities that emit more than 100 tons/yr of SO_2, NO_x, HC, CO, or particulate matter [Ref. 1]. Of these sources, 65 were included in the count of large fuel combustion sources. If it is assumed that

*References are listed in Sec. 4.3.

**This was the emission inventory used to analyze the Air Pollution Implementation Plan for Illinois.

all 383 facilities are manufacturers, then the total number of manufacturers required to submit and review action plans is 455. Of these only 189 are large HC or NO_x emission sources; i.e., N = 189.

The value of T is set equal to \$0.10. The telephone calls are assumed to be made and received by lower level management employees. Based on a survey of wages made in metropolitan areas throughout the country, the median monthly income of a Personnel Director I is \$1,416.* This wage rate is assumed to be an average for all lower level managers in the Chicago SMSA; therefore, $W = \overline{W} = \$1,416$.

Substituting the above values of N, T, W and $\overline{W}$ into Eq. 4.1 results in the estimated notification cost of \$125 given in Table 4.1.

Cost of Reviewing Action Plans

The task of reviewing action plans is neither difficult nor time-consuming; presumably, the primary purpose of the review is to prepare management for the possibility of a red alert or emergency. The cost of the review is estimated as:

$$\overline{C} = N \cdot \hat{W} \cdot \overline{T} \tag{4.2}$$

where:

$\overline{C}$ ≡ the cost of reviewing action plans,

N ≡ the number of manufacturing plants,

$\hat{W}$ ≡ the average monthly salary of those making the review, and

$\overline{T}$ ≡ the average time taken to review the action plans.

The value of N is 189, as discussed above. The cost of reviewing action plans is estimated by assuming that a plant manager for each manufacturing facility spends a total of 30 minutes reviewing the action plan. This assumption may be conservative, since most action plans are short documents and, with the likelihood of several yellow alerts occurring during each ozone season, the manager would become familiar with the action plan during the season. The monthly salary of a plant manager is assumed to be the same as the median monthly salary of a Personnel Director III which was \$2,043 (from Table A.5), i.e., $\hat{W} = 2043$, in 1974. Assuming a working month of 21 eight-hour days, 30 minutes (one-half hour) is 1/336 of a month, so, $\overline{T} = 1/336$.

Substituting the above values of N, $\hat{W}$, and $\overline{T}$ into Eq. 4.2 results in an estimated cost of reviewing action plans of $1,149.

Cost of Inspecting Emission Control Devices

The cost of inspecting emission control devices is estimated using Eq. 4.2 with the following variable definitions:

$N \equiv$ the number of manufacturing plants,

$\hat{W} \equiv$ the average monthly salary of those making the inspection, and

$\overline{T} \equiv$ the average time taken to inspect the devices at each plant.

A Class V Engineer earning $1,691 per month (from Table A.5) is assumed to make the inspection, which is assumed to require two hours (1/84 of a month's working hours). It is further assumed that only those firms required to develop an action plan have control equipment, i.e., $N = 189$. The cost of inspection, calculated by substituting these N, $\hat{W}$, and $\overline{T}$ values into Eq. 4.2, then becomes $3,804.

4.2 EMISSION REDUCTION EFFECTS OF ACTION 2

The effectiveness of this action in reducing HC and NO_x emissions would probably be minimal. The review of action plans is principally a preparatory step in case more serious alert levels are reached. Inspecting emission control devices would not result in a significant reduction of HC and NO_x because these pollutants are not commonly controlled, as are SO_2 and particulate matter. The third step of Action 2 requires that delayable operations be identified, but it is implied that only delayable operations, which do not adversely affect normal production, should be curtailed. The fact that normal production would not be curtailed seems to indicate that emissions would be affected very little. It is assumed that HC and NO_x emissions are not reduced by this action.

4.3 REFERENCES

1. Coblenz, J., Illinois Environmental Protection Agency, personal communication (March 1976).

2. *Proposed Amendments to Chapter 2, Part IV, Episodes*, Illinois Environmental Protection Agency, p. 5 (Dec. 15, 1975).

5 REQUEST TO REDUCE ELECTRIC POWER STATION EMISSIONS THROUGH SYSTEM WIDE ADJUSTMENT -- ACTION 3

During a yellow alert, electric power generating stations burning fossil fuels are requested to reduce emissions in and into the affected area to the greatest extent practicable by adjusting operations system wide or by any other means approved by the Illinois EPA.

Electric utilities can reduce emissions in the affected area by switching generation to plants outside the area or by using natural gas in plants having a dual fuel capability. Fuel switching is generally more expensive than load switching, therefore, we assume that during a yellow alert power companies will rely on load switching to comply with the regulation. This is a reasonable simplification since power companies are only *requested* to reduce emissions, and expensive compliance options will most likely be avoided.

Because of the complexity of the options available to power companies, a computer program was written to simulate possible load switching and fuel switching options. The program calculates the cost and emissions of alternative loading patterns and demand schedules. Details of the program are presented in Appendix B. The resulting costs and effects are summarized in Table 5.1.

Table 5.1. Summary of the Costs and Emission Reduction Effects of Load Switching by Electric Utilities

Episode Length (days)	Costs ($\$10^3$)			Emission Reductions (tons)	
	Notification	Load Switching	Total	HC	NO_x
1	0.008	26.9	26.9	0.208	12.5
2	0.016	53.7	53.7	0.416	24.9
3	0.024	80.6	80.6	0.624	37.4
4	0.032	107	107	0.832	49.9
5	0.040	134	134	1.04	62.3

5.1 COSTS OF ACTION 3

The costs of Action 3 include the costs of notifying the power company of the yellow alert and increased operating costs resulting from load switching. The data and assumptions used to estimate these costs are presented below.

Notification Cost

The power company is assumed to be notified of a yellow alert by telephone. Assuming the call lasts two minutes, the notification cost is estimated to be:

$$C = N \cdot (T + W/5040 + \overline{W}/5040) \tag{5.1}$$

where:

$C \equiv$ the notification cost,

$N \equiv$ the number of telephone calls required,

$T \equiv$ the cost of a telephone call,

$W \equiv$ the monthly wage rate of the person making the telephone call,

$\overline{W} \equiv$ the monthly wage rate of the person receiving the telephone call, and

The constant 5040 is the number of two-minute time periods in a working month (i.e., in 21 eight-hour days).

Since there is only one power company, only one call is required; however, it is possible that each fossil fuel power station will have to be notified. If this occurs, then a maximum of 12 calls will be required, i.e., $N = 12$. The value of T is set equal to \$0.10, and the telephone calls are assumed to be made and received by lower level management employees. It is assumed that the monthly salary of these employees is the same as that of a Personnel Director I, i.e., \$1,416.* Therefore, $W = \overline{W} = \$1,416$. Substituting these values of N, T, W and $\overline{W}$ into Eq. 5.1 results in an estimated notification cost of \$7.94. Notification is assumed to be made on each day of the episode; the notification costs for various length episodes are presented in Table 5.1.

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*See Table A.5.

Load Switching Cost

The load switching cost is estimated by loading fossil fuel power plants outside of the Chicago SMSA before fossil fuel plants within the area are loaded. Four steam plants are located outside the Chicago SMSA: Dixon, Kincaid, Powerton, and Sabrooke. Using a standard day with a peak demand of 11,500 MWh, as discussed in Appendix B, and loading the four non-Chicago SMSA plants prior to loading the Chicago SMSA plants, results in the costs presented in Table 5.2. This table shows the estimated operating cost for each plant with and without load switching, and the total estimated cost of load switching: $30,661, which is assumed to occur each day of an episode. This cost is in 1976 dollars; in 1974 dollars it is $30,661(147.7/168.6) = $26,860.* The load switching costs for episodes of various lengths are presented in Table 5.1.

5.2 EMISSION REDUCTION EFFECTS OF ACTION 3

Emission reductions are estimated by multiplying an emission factor in tons/kWh by the kWh generated at each power station unit. The emission factors are based on the fuel used and the efficiency of the unit. Complete details of the procedure and data used are provided in Appendix B.

Table 5.3 shows the estimated emissions for each of the Chicago SMSA power plant units with and without load switching. The estimated emission reductions per day of Action 3 are 0.208 tons of hydrocarbons and 12.5 tons of NO_x.

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*See Table A.6 for Consumer Price Index Data.

Table 5.2. Estimated Daily Operating Costs for Power Generation with and without Load Switching

Plant Name and Unit #	Loading Order A[a]	Loading Order B[b]	Operating Costs (1976 $) A	Operating Costs (1976 $) B	Operating Costs (1976 $) Difference (A-B)
Chicago SMSA					
Crawford, #6[c]	33	31	0	0	0
Crawford, #7	21	18	35,856	35,856	0
Crawford, #8	17	13	72,399	75,103	2,704
Fisk, #18	27	25	22,620	22,620	0
Fisk, #19	19	15	53,242	62,065	-8,823
Joliet, #5	25	23	11,432	11,432	0
Joliet, #6	20	16	37,460	48,863	-11,403
Joliet, #7	15	11	122,114	122,496	-382
Joliet, #8	14	10	123,341	126,146	-2,805
Ridgeland, #1[c]	31	29	0	0	0
Ridgeland, #2[c]	32	30	0	0	0
Ridgeland, #3[c]	29	27	0	0	0
Ridgeland, #4[c]	30	28	0	0	0
State Line, #1	28	26	23,098	23,098	0
State Line, #2	26	24	20,448	20,448	0
State Line, #3	13	9	45,259	45,655	-396
State Line, #4	16	12	79,751	80,712	-961
Waukegan, #5	12	8	20,958	20,958	0
Waukegan, #6	11	7	14,499	14,499	0
Waukegan, #7	10	6	44,803	45,303	-500
Waukegan, #8	9	5	42,952	43,556	-604
Will County, #1	24	20	27,324	27,324	0
Will County, #2	24	21	27,562	27,562	0
Will County, #3	18	14	57,722	60,218	-2,496
Will County, #4	22	19	90,432	90,432	0
Non-SMSA					
Dixon, #4	6	22	13,534	7,668	5,866
Dixon, #5	5	17	16,633	8,878	7,755
Kincaid, #1	4	4	73,655	73,922	-267
Kincaid, #2	3	3	75,945	76,304	-359
Powerton, #5	1	1	114,443	114,443	0
Powerton, #6	2	2	107,748	108,922	-1,174
Sabrooke, #3	8	33	20,844	0	20,844
Sabrooke, #4	7	32	29,069	0	29,069
TOTAL COSTS	--	--	1,425,136	1,394,475	30,661

[a]With load switching.

[b]Without load switching.

[c]For the "typical day" used in the analysis, these units, the most expensive to operate, are not used.

Table 5.3. Estimated Daily Emissions with and without Load Switching

Plant Name and Unit # (Chicago SMSA)	Hydrocarbons (tons)			Nitrogen Oxides (tons)		
	A[a]	B[b]	Difference (A-B)	A[a]	B[b]	Difference (A-B)
Crawford, #6[c]	0	0	0	0	0	0
Crawford, #7	0.195	0.195	0	11.7	11.7	0
Crawford, #8	0.454	0.471	-0.017	27.3	28.3	-1.0
Fisk, #18	0.171	0.171	0	10.2	10.2	0
Fisk, #19	0.370	0.432	-0.062	22.2	25.9	-3.7
Joliet, #5	0.063	0.063	0	3.79	3.79	0
Joliet, #6	0.242	0.315	-0.073	14.5	18.9	-4.4
Joliet, #7	0.820	0.823	-0.003	49.2	49.4	-0.2
Joliet, #8	0.846	0.866	-0.020	50.7	51.9	-1.2
Ridgeland, #1[c]	0	0	0	0	0	0
Ridgeland, #2[c]	0	0	0	0	0	0
Ridgeland, #3[c]	0	0	0	0	0	0
Ridgeland, #4[c]	0	0	0	0	0	0
State Line, #1	0.180	0.180	0	10.8	10.8	0
State Line, #2	0.133	0.133	0	8.01	8.01	0
State Line, #3	0.276	0.279	-0.003	16.6	16.7	-0.1
State Line, #4	0.483	0.489	-0.006	29.0	29.3	-0.3
Waukegan, #5	0.217	0.217	0	13.0	13.0	0
Waukegan, #6	0.167	0.167	0	10.0	10.0	0
Waukegan, #7	0.469	0.474	-0.005	28.1	28.4	-0.3
Waukegan, #8	0.418	0.424	-0.006	25.1	25.4	-0.3
Will County, #1	0.175	0.175	0	10.5	10.5	0
Will County, #2	0.167	0.167	0	10.0	10.0	0
Will County, #3	0.345	0.359	-0.014	20.7	21.6	-0.9
Will County, #4	0.523	0.523	0	31.4	31.4	0
TOTAL EMISSIONS	6.71	6.92	-0.208	403	415	-12.5

[a]With load switching.

[b]Without load switching.

[c]For the "typical day" used in the analysis, these units, the most expensive to operate, are not used.

6 PUBLIC REQUESTED TO AVOID UNNECESSARY USE OF ELECTRICITY -- ACTION 4

During a yellow alert, the public is requested to avoid unnecessary use of electricity. Since compliance with Action 4 is voluntary, the impact of the regulation depends on how the public defines "unnecessary electricity" and how many individuals reduce their electricity consumption. Rather than trying to speculate about these variables, the costs and effects of Action 4 are estimated for demand reductions of 0, 2, 5, and 10%. The actual demand reduction will most likely fall in this range. The cost and effect estimates in Table 6.1 are based on a 2% electricity demand reduction.

6.1 COSTS OF ACTION 4

The costs of Action 4 include the cost of notifying the public of the yellow alert and requesting a reduction in electricity consumption, and the cost associated with reduced electricity consumption.

Notification Cost

Radio and TV announcements are assumed used to notify the public of a yellow alert and ask them to reduce electricity consumption. The cost of these announcements, derived in Appendix D, is $6,800/day, as shown in Table 6.1.

Table 6.1. Summary of the Costs and Emission Reduction Effects of Avoiding Unnecessary Use of Electricity[a]

Episode Length (days)	Costs ($\$10^3$)			Emission Reductions (tons)	
	Notification	Net Revenue Loss	Total	HC	NO_x
1	6.80	22.7	29.5	0.461	22.3
2	13.6	45.4	59.0	0.922	44.6
3	20.4	68.1	88.5	1.38	66.9
4	27.2	90.8	118	1.84	89.2
5	34.0	114	148	2.31	112

[a]Assuming a 2% electricity demand reduction (i.e., a reduction of 4,826 MWh from "typical day" demand of 241,318 MWh).

Net Revenue Loss

The social cost associated with reduced electricity consumption is the foregone satisfaction derived from the consumption of electricity for washing, lighting, entertainment, etc. It is assumed that this cost is equal to the foregone expenditure for electricity.

When electricity demand is reduced some resources (e.g., fuel) used to produce electricity are saved and can be utilized elsewhere in the economy. This saving is a social benefit of reduced electricity consumption. The combined effect of the satisfaction loss and the resource saving is:

$$C = P \cdot \delta - U(\delta) \qquad (6.1)$$

where:

$C \equiv$ the social cost of reduced electricity consumption,

$P \equiv$ the price of electricity (\$/MWh),

$\delta \equiv$ MWh of electricity foregone, and

$U(\delta) \equiv$ the savings of resources used to produce electricity, which is a function of the amount of electricity not produced.

Because of the assumptions used to quantify the social cost of reduced electricity consumption, the variable C in Eq. 6.1 is also equal to the net revenue loss to the power company. This is easily seen since $P \cdot \delta$ equals the gross revenue that would have been received from the foregone electricity consumption and $U(\delta)$ is the operating cost of producing the last δ MWh of electricity. Although the net revenue loss interpretation is more easily understood than the social cost interpretation, it should be kept in mind that they are equivalent given the assumptions used in the analysis.

To estimate the net revenue loss, the value of δ is assumed to be between 0 and 10% of the total electricity consumption during a "typical" day of 241,318 MWh.* The 1974 ex post average price paid for electricity, P, was $24.79/MWh,** and the value of $U(\delta)$ is estimated using the computer simulation model described in Appendix B.

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*See Appendix B for the definition of a typical episode day.

**The 1974 ex post average price of electricity in Illinois can be calculated from the total revenues and energy sales of Illinois electric utilities which appear in *Statistical Year Book of the Electric Utility Industry*, Edison Electric Institute, Tables 22S (p.33) and 36S (p.45) (1975).

Table 6.2 summarizes the results of using the above data in Eq. 6.1 for electricity demand reductions of 0, 2, 5, and 10%. Interpolation between these estimates will provide a reasonable estimate of the net revenue loss (social cost) of demand reductions not listed in the table. However, extrapolation beyond 10% may not be appropriate.

6.2 EMISSION REDUCTION EFFECTS OF ACTION 4

The emission reduction effects of Action 4 are estimated using the computer program described in Appendix B. The emission reductions resulting from demand reductions of 0, 2, 5, and 10% are summarized in Table 6.3.

Table 6.2. Net Revenue Losses Due to Action 4

% Demand Reduction[a]	Gross Revenue Loss (A) ($)	Operating Cost Savings (B) ($)	Net Revenue Loss (A-B)[b] ($)
0	0	0	0
2	119,650	96,952	22,699
5	299,119	242,317	56,802
10	598,232	474,869	123,363

[a] 2% reduction = 4,826 MWh foregone on a "typical day," 5% reduction = 12,066 MWh, 10% reduction = 24,132 MWh.

[b] This is the social cost of reduced electricity consumption given the assumptions used in the analysis.

Table 6.3. Emission Reduction Effects of Action 4

% Demand Reduction	HC Emission Reductions (tons)			NO_x Emission Reductions (tons)		
	Steam Plants	Peakers	Total	Steam Plants	Peakers	Total
0	0	0	0	0	0	0
2	0.291	0.170	0.461	17.5	4.80	22.3
5	0.711	0.420	1.13	42.7	12.0	54.7
10	1.27	0.837	2.11	76.4	23.6	100

6.3 SENSITIVITY ANALYSIS FOR ACTION 4

The cost and effects of Action 4 are highly dependent on the assumed demand reduction δ. For demand reductions between 0 and 10%, the cost of Action 4 for a one-day episode ranges between 0 and $130,163. However, the efficiency of Action 4, measured as the cost/effectiveness ratios of HC and NO_x reduction, is not very sensitive to the values of δ between 2 and 10%, as shown in Table 6.4.

Table 6.4. Cost/Effectiveness Ratios for Action 4 for a One-Day Episode

% Demand Reduction[a]	Cost/Effectiveness Ratios ($\$10^3$/ton)		
	HC	NO_x	HC and NO_x
2	64.0	1.32	1.30
5	56.3	1.16	1.14
10	61.7	1.30	1.27

[a] 2% reduction = 4,826 MWh foregone on a "typical day," 5% reduction = 12,066 MWh, 10% reduction = 24,132 MWh.

7 PUBLIC REQUESTED TO LIMIT AIR CONDITIONING -- ACTION 5

During a yellow alert the public is requested to limit space heating to 65°F and air conditioning to 80°F. Because the ozone season occurs during the warmer months of the year, only the impact of voluntarily setting thermostats at 80°F is evaluated.

Two points should be remembered regarding the effects of Action 5: (1) the action is a request, not an enforced order, and (2) air conditioning is not supposed to be turned off, but rather set at 80°, which is somewhat above the normal setting. For these reasons, one would expect only a partial reduction in the heat sensitive demand to result from Action 5. The cost and emission reduction effects are calculated for air conditioning demand reductions of 0, 5, 10, and 25%. The results in Table 7.1 are based on a 5% reduction in air conditioning electricity demand.

7.1 COSTS OF ACTION 5

The costs of Action 5 include the cost of notifying the public of the yellow alert and requesting the change in thermostat setting, and the cost associated with reduced electricity consumption for air conditioning.

Table 7.1. Summary of the Costs and Emission Reduction Effects of Raising Thermostats to 80°F[a]

Episode Length (days)	Costs ($\$10^3$)			Emission Reductions (tons)	
	Notification	Net Revenue Loss	Total	HC	NO_x
1	6.80	15.7	22.5	0.188	8.45
2	13.6	31.3	44.9	0.376	16.9
3	20.4	47.0	67.4	0.564	25.4
4	27.2	62.7	89.9	0.752	33.8
5	34.0	78.3	112	0.940	42.3

[a]Assuming a 5% reduction in air conditioning electricity demand (i.e., a reduction of 2,497 MWh from a "typical day" demand of 241,318 MWh).

Notification Cost

Radio and TV announcements are assumed to be used to notify the public of a yellow alert and ask them to change their thermostat settings. The cost of these announcements, derived in Appendix D, is $6,800/day, as shown in Table 7.1.

Net Revenue Loss

The social cost associated with reduced electricity consumption for air conditioning is the foregone satisfaction (comfort) derived from air conditioning. It is assumed that this cost is equal to the foregone expenditure for electricity.

When electricity demand is reduced some resources (e.g., fuel) used to produce electricity are saved and can be utilized elsewhere in the economy. This saving is a benefit of reduced electricity consumption. The combined effect of the satisfaction loss and the resource saving is:

$$C = P \cdot \delta - U(\delta) \tag{7.1}$$

where:

$C \equiv$ the social cost of reduced electricity consumption for air conditioning,

$P \equiv$ the price of electricity ($/MWh),

$\delta \equiv$ MWh of electricity foregone, and

$U(\delta) \equiv$ the savings of resources used to produce electricity, which is a function of the amount of electricity not produced.

Because of the assumptions used to quantify the social cost of reduced electricity consumption, Eq. 7.1 also can be interpreted as the net revenue loss to the power company. For more details see Sec. 6.1.

The electricity demand originating from air conditioners is not easily isolated from total electricity demand. A Commonwealth Edison load model estimates a 5,300 MWh heat sensitive component based on peak-making weather information [Ref. 1]. The summer's peak-making weather would cause a total peak demand of about 14,000 MWh, therefore, the non-heat-sensitive summer peak demand is 14,000 - 5,300 = 8,700 MWh. As described in Appendix B, an 11,500 MWh peak is being assumed as the expected peak during a "typical" day. The difference between the 11,500 MWh peak and the 8,700 MWh non-heat-sensitive

peak demand is 2,800 MWh.

Approximately 15% of Commonwealth Edison's service area is outside the Chicago SMSA and, therefore, must be excluded from the estimation. Thus, the peak electricity demand from air conditioning within the Chicago SMSA is estimated to be 2,800 • 0.85 = 2,380 MWh, which is about 20.7% of the peak hourly demand of 11,500 MW. Therefore, 5, 10, and 25% reductions in air conditioning electricity demand are equivalent to 1.04, 2.07, and 5.18% reductions in total electricity demand (e.g., 0.05 • 20.7 = 1.04).

To estimate the net revenue loss, the value of δ is assumed to be between 0 and 5.18% of the total electricity consumption during a "typical" day of 241,318 MWh. The 1974 ex post average price paid for electricity, P, was $24.79/MWh.* The value of $U(\delta)$ is estimated using the computer simulation model described in Appendix B.

Table 7.2 summarizes the results of using the above data in Eq. 7.1 for air conditioning electricity demand reductions of 0, 5, 10, and 25%. Interpolation between these estimates will provide a reasonable estimate of the net revenue loss (social cost) of demand reductions not listed in the table. However, extrapolation beyond 25% may not be appropriate.

Table 7.2. Net Revenue Losses Due to Action 5

% Air Cond. Demand Reduction[a]	Gross Revenue Loss (A) ($)	Operating Cost Savings (B) ($)	Net Revenue Loss (A-B)[b] ($)
0	0	0	0
5	61,910	46,242	15,668
10	123,814	100,060	23,754
25	309,522	250,069	59,453

[a] 5% air conditioning demand reduction (or 1.04% total electricity demand reduction) = 2,497 MWh foregone on a "typical day," 10% (or 2.07%) = 4,994 MWh, and 25% (or 5.18%) = 12,486 MWh.

[b] This is the social cost of reduced electricity consumption given the assumptions used in the analysis.

*Calculated from data in Ref. 2.

Table 7.3. Emission Reduction Effects of Action 5

% Air Cond. Demand Reduction[a]	HC Emission Reductions (tons)			NO_x Emission Reductions (tons)		
	Steam Plants	Peakers	Total	Steam Plants	Peakers	Total
0	0	0	0	0	0	0
5	0.099	0.089	0.188	5.96	2.49	8.45
10	0.298	0.177	0.475	17.9	5.15	23.1
25	0.728	0.443	1.17	43.7	12.4	56.1

[a]5% air conditioning demand reduction (or 1.04% total electricity demand reduction) = 2,497 MWh foregone on a "typical day," 10% (or 2.07%) = 4,994 MWh, and 25% (or 5.18%) = 12,486 MWh.

7.2 EMISSION REDUCTION EFFECTS OF ACTION 5

The emission reduction effects of Action 5 are estimated using the computer program described in Appendix B. The emission reductions resulting from air conditioning demand reductions of 0, 5, 10, and 25% are summarized in Table 7.3.

7.3 SENSITIVITY ANALYSIS FOR ACTION 5

The cost and effects of Action 5 are highly dependent on the assumed demand reduction δ. The impacts of various values of δ can be inferred from the discussion in Sec. 6.3.

7.4 REFERENCES

1. Fancher, James, Commonwealth Edison Company, personal communication (July 16, 1976).

2. *Statistical Year Book of the Electric Utility Industry*, Edison Electric Institute, Tables 22S (p. 33) and 36S (p. 45) (1975).

8 RESTRICTIONS ON REFUSE INCINERATION -- ACTION 6

During a yellow alert governmental or commercial installations established primarily for the burning of refuse must postpone delayable incinerations; all other incineration and all open burning is prohibited. To estimate the economic consequences of these actions, it is assumed that municipal and commercial waste incinerators reduce combustion by altering their storage/incineration schedules. It is assumed that smaller incinerators comply with the regulation by delaying waste incineration or landfilling waste during the alert. A summary of the costs and emission reduction effects of Action 6 are presented in Table 8.1.

8.1 COSTS OF ACTION 6

The costs of restricting refuse incineration are the (1) costs of notifying the incinerator operators of a yellow alert, (2) landfill costs for the smaller incinerators, and (3) rescheduling costs for municipal and commercial incinerators.

Notification Cost

The three Chicago incinerator operators are assumed to be notified by telephone on the first day of a yellow alert at a cost of $2 (see Chapter 19). Small incinerator operators are assumed to be notified through radio and TV announcements, estimated to cost $6,800/day (see Appendix D). For an n-day episode the notification costs are 6,800•n + 2; these costs, for various length episodes, are presented in Table 8.1.

Table 8.1. Summary of the Costs and Emission Reduction Effects of Restricting Refuse Incineration

Episode Length (days)	Costs (10^3) Notification	Landfill	Rescheduling	Total	HC Emission Reductions (tons) Municipal Incin.	Private Incin.	Total	NO_x Emission Reductions (tons) Municipal Incin.	Private Incin.	Total
1	6.80	1.08	0.042	7.92	1.28	9.00	10.3	2.56	2.50	5.06
2	13.6	2.16	0.083	15.8	2.30	18.0	20.3	4.59	5.00	9.59
3	20.4	3.24	0.125	23.8	2.50	27.0	29.5	5.00	7.50	12.5
4	27.2	4.32	0.167	31.7	2.50	36.0	38.5	5.00	10.0	15.0
5	34.0	5.40	0.209	39.6	2.50	45.0	47.5	5.00	12.5	17.5

Landfill Cost

Virtually no data were obtained concerning the small incinerators. A rough estimate of 2,000 small incinerators located in the Chicago area was provided by the Illinois EPA. No additional information was available. However, the landfill costs can be estimated as:

$$C = 2000 \cdot \tau \cdot L \cdot \alpha \tag{8.1}$$

where:

$C \equiv$ the landfill cost,

$\tau \equiv$ the average number of tons of refuse incinerated daily by each small incinerator,

$L \equiv$ the cost of landfilling a ton of waste, and

$\alpha \equiv$ the fraction of waste landfilled.

The average cost of landfilling a ton of waste in the Chicago area in 1970 was $4.25 [Ref. 6];* in 1974 dollars this is $5.40/ton.** Since postponing incineration is a relatively easy task for small incinerators, it is assumed that most of the incineration is delayed until the episode is over rather than landfilling the waste during the episode. For this reason, $\alpha = 0.1$. Setting $\tau = 1$ will provide a "normalized" cost of landfilling. That is, if $\bar{\tau}$ is the actual number of tons of waste burned by each of the small incinerators, then the estimated landfill cost for an n-day alert would be:

$$\bar{C} = C \cdot \bar{\tau} \cdot n \tag{8.2}$$

where $C = 2000 \cdot 1 \cdot 5.40 \cdot 0.1 = \$1,080$. In Table 8.1 the normalized values of landfilling, i.e., $C \cdot n$, are presented for a yellow alert of various lengths.

Rescheduling Cost

In the Chicago SMSA the City of Chicago operates three refuse incinerators [Ref. 2]. A commercial incinerator operated by Waste Management Incinerator, Inc., was converted to a transfer station in October 1976 [Ref. 7]. These are the only municipal or commercial refuse incinerators presently operating in the Chicago SMSA [Ref. 5]. In 1973 there were eight municipal

*References are listed in Sec. 8.4.

**See Table A.6 for Consumer Price Indexes for 1970 and 1974.

and commercial waste incinerators operating in the Chicago area. For this analysis only the costs for three Chicago incinerators will be estimated. This is a reasonable simplification since there has been a decline in the number of incinerator operations in the last few years and there are no new incinerators planned for the area.

The rescheduling costs are estimated using the following equation:

$$C' = N \cdot T \cdot W/168 \qquad (8.3)$$

where:

$C' \equiv$ the rescheduling cost,

$N \equiv$ the number of incinerator operations requiring rescheduling,

$T \equiv$ the number of hours required for the rescheduling,

$W \equiv$ the monthly wage rate of the person doing the rescheduling, and

The constant 168 is the number of hours in a working month (i.e., $21 \cdot 8 = 168$).

It is assumed that two hours a day are required for the chief operator of each incinerator to reschedule operations and ensure that the new schedule is implemented, thus, T = 2 hr. The monthly salary of a plant operator is assumed to be equal to the median salary of an Engineer II, which is $1,170, i.e., W = $1,170/month.* Since there are three incinerators, N = 3. Substituting these values into Eq. 8.3 gives C' = $41.79/day. For an n-day yellow alert, the rescheduling cost is $41.79·n, as shown in Table 8.1.

8.2 EMISSION REDUCTION EFFECTS OF ACTION 6

Municipal Incinerators

The potential reductions in waste incineration during episodes of various lengths are calculated by adjusting the incineration/storage schedule provided in Table 19.4. The results of these calculations are provided in Table 8.2. The waste reduction figures are estimated assuming that at least 709 tons/day need to be incinerated to provide enough heat to avoid damage to equipment and meet contractural commitments for steam. This minimum operating level is estimated from the required 2.54×10^8 Btu/hr [Ref. 4] of supplemental fuel energy that would be required if no waste is incinerated and

*From Table A.5.

Table 8.2. Maximum Reductions in Waste Incineration during an Episode through Rescheduling

Episode Length (days)	Reductions in Waste Incineration (tons)							
	Day Episode Begins							
	Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.	Sun.	Average
1	1761	1761	1761	1761	1360	1761	1761	1704
2	3522	3336	2348	1360	3830	3522	3522	3063
3	3336	2348	1360	372	6300	5312	4324	3336
4	2348	1360	372	6300	5312	4324	3336	3336
5	1360	372	6300	5312	4324	3336	2348	3336

by setting the average heat value of municipal waste equal to 4300 Btu/lb [Ref. 1]: 709 tons/day = [(2.54 x 10^8 Btu/hr) ÷ (4300 Btu/lb · 2000 lb/ton)]· 24 hr/day.

Using the emission factors for refuse incineration found in Ref. 3 of 1.5 lb HC/ton of waste and 3.0 lb NO_x/ton of waste and the average potential waste reduction in Table 8.2, the potential emission reductions for municipal incinerators shown in Table 8.1 are calculated.

Private Incinerators

Assuming an average of one ton of waste incinerated daily per private incinerator ($\tau = 1$), the prohibition of incineration in the 2,000 small private incinerators will reduce hydrocarbon emissions by 9.0 tons/day and nitrogen oxides emissions by 2.5 tons/day.* These emission reductions are summarized in Table 8.1.

8.3 SENSITIVITY ANALYSIS FOR ACTION 6

The results for private incinerations are based on the assumptions that (1) an average of one ton of waste is incinerated each day by each small

*These estimates are based on the mid-range emission factors for industrial/ commercial incinerators as given in Ref. 3, i.e., 9.0 lbs HC/ton of waste and 2.5 lbs NO_x/ton of waste. The emission reduction for HC is thus: [2000 incinerators]·[9.0 lbs HC/ton of waste]·[τ (tons of waste/incinerator/day]· [1 ton HC/2000 lb HC] = 9.0 tons HC/day. Similarly, the emission reduction for NO_x is: 2000 · 2.5 · τ/2000 = 2.5 tons NO_x/day.

incinerator and (2) 90% of the incineration can be delayed until the episode is over, i.e., $\tau = 1$ and $\alpha = 0.1$. The maximum value of τ is open ended. However, the costs to private incinerators and the emission reduction effects are both proportional to τ. Therefore, if the notification cost is not considered, the cost/effectiveness ratios (10^3/ton) of controlling private incinerators are independent of τ (e.g., $\$10^3$/ton HC = 1.08/9.00 = 0.120, when $\alpha = 0.1$).

On the other hand, α ranges between 1 and 0, making landfill costs range between \$10,800 and 0 for a one-day episode when $\tau = 1$. This would make the total cost of Action 6 for a one-day episode range between \$17,642 and \$6,042. The cost/effectiveness ratio for private incineration ranges between 10.8/9.0 = 1.20 to 1.08/9.0 = 0.120 as α ranges between 1 and 0.1. Although the efficiency of Action 2 is quite sensitive to the assumption about α, the worst case still indicates that controlling small incinerators is efficient relative to some other control activities (see Chapter 25).

8.4 REFERENCES

1. American Incineration Association Standard.

2. Callahan, Supt. J. F., and E. F. Nigro, City of Chicago Department of Streets and Sanitation, personal communication (1976).

3. *Compilation of Air Pollution Emission Factors*, U.S. EPA, AP-42 (March 1975).

4. Degnan, F. J., Acting Commissioner, City of Chicago Department of Streets and Sanitation, personal communication (Sept. 27, 1976).

5. Harden, Larry, Illinois Institute for Environmental Quality, personal communication (1976).

6. Hockman, O., et al., *The Environmental Costs of Landfills and Incinerators*, The University of Chicago and Argonne National Laboratory (July 1976).

7. Rooney, Phil, Waste Management Incinerator, Inc., personal communication (1976).

9 CURTAILING FLEET VEHICLE OPERATIONS -- ACTION 7

During a red alert fleet vehicles may not be dispatched or operated in or into the red alert area. This provision does not apply to vehicles being used for mass transit; grocery, pharmaceutical, and essential fuel delivery; emergency medical services; and comparable purposes designated by the Illinois EPA.

Fleet vehicles are defined in the regulation as "any one of three or more vehicles operated for the transportation of persons or property in the furtherance of commercial or industrial enterprises, for hire or not for hire"; this definition implies that government fleets are not affected by Action 7. Government fleet operations are curtailed by other provisions of the ozone regulation. The costs and emission reduction effects of Action 7 are provided in Table 9.1.

Table 9.1. Summary of the Costs and Emission Reduction Effects of Curtailing Fleet Vehicle Operations

Episode Length (days)	Costs ($\$10^3$)								
	Notification	Rescheduling	Shut-Down, Start-Up	Delayed Deliveries	Overtime	Canceled, Delayed Trips[a]	Alt. to Taxis, Livery	Through Traffic Diversion	Total
1	6.89	114	169	19.5	1,340	572	160	78.9	2,460
2	13.7	227	169	44.5	2,680	1,140	320	158	4,750
3	20.5	341	169	75.1	4,020	1,720	480	237	7,060
4	27.3	454	169	111	5,360	2,300	640	315	9,380
5	34.1	568	169	153	6,700	2,880	801	394	11,700

Table 9.1. (Cont'd)

Episode Length (days)	HC Emission Reductions (tons)			NO_x Emission Reductions (tons)[b]
	Vehicular Sources	Evaporative Sources	Total	
1	96.3	35.2	132	66.4
2	193	70.4	263	133
3	289	106	395	199
4	385	141	526	266
5	481	176	657	332

[a]Some persons that would use rental cars are assumed to cancel or delay their trips.

[b]Only vehicular source emissions.

9.1 COSTS OF ACTION 7

The costs of Action 7 include those of notification, rescheduling, shut-down/start-up, delayed deliveries, overtime, canceled or delayed trips, alternatives to taxi/livery services, and diversion of through traffic.

Notification Cost

It is assumed that the largest firms with fleet vehicles are informed by telephone that a red alert has been called. If each telephone call lasts two minutes, then the cost of these calls is:

$$C = N \cdot (T + W/5040 + \overline{W}/5040) \tag{9.1}$$

where:

$C \equiv$ the cost of making the telephone calls,

$N \equiv$ the number of telephone calls made,

$T \equiv$ the cost of a single telephone call,

$W \equiv$ the monthly wage of the person making the call,

$\overline{W} \equiv$ the monthly wage of the person receiving the call, and

The constant 5,040 is the number of two-minute time periods in a working month (i.e., in 21 eight-hour days).

Telephone calls are assumed to be made to large trucking firms within the Chicago SMSA, i.e., firms with more than 100 employees. In 1973 there were 117 large trucking establishments (SIC 421) in the six-county area [Ref. 6];* it is assumed this was the number of large trucking firms in 1974. Large chain department and furniture stores that have truck delivery operations are assumed to be contacted by telephone; nine such stores were identified in the study. The two largest taxi companies and the four utility companies in the Chicago SMSA are also assumed to be telephoned. Therefore, the total number of telephone calls is: $N = 117 + 9 + 2 + 4 = 132$.

Setting $T = \$0.10$ and $W = \overline{W} = \$1,416$, the assumed average monthly salary of lower level management personnel (see Director of Personnel I, Table A.5), the telephone notification cost is estimated to be, from Eq. 9.1, \$87.37.

The employees of the firms affected by Action 7 are assumed to be briefed in advance of their responsibilities if a red alert is called. There-

*References are listed in Sec. 9.4.

fore, radio and TV announcements are assumed sufficient to notify them of a red alert. These announcements will also notify the smaller firms of a red alert. The cost of radio and TV announcements, estimated in Appendix D, is \$6,800/day. If the telephone calls are only made on the first day of the episode, then the notification cost of Action 7 for an n-day episode is:

$$\overline{C} = 6800 \cdot n + 87.37 \tag{9.2}$$

This cost for episodes of various lengths is provided in Table 9.1.

Rescheduling Cost

A rescheduling cost will be incurred by fleet vehicle operators since each must reschedule delivery dates and/or workers' schedules. If α is the average number of minutes required by lower level management personnel to reschedule each vehicle, then the rescheduling cost for an n-day episode is:

$$\tilde{C} = (\tilde{N} \cdot \tilde{W} \cdot \alpha / 10{,}080) \cdot n \tag{9.3}$$

where:

$\tilde{C} \equiv$ the rescheduling cost,

$\tilde{N} \equiv$ the number of vehicles requiring rescheduling,

$\tilde{W} \equiv$ the monthly wage rate of the person doing the rescheduling, and

The constant 10,080 is the number of minutes in a working month of 21 eight-hour days.

Table 9.2 summarizes our estimate of the number of fleet vehicles that operate in the Chicago SMSA and are subject to the provisions of Action 7. The data, assumptions, and methods used to estimate the number of fleet vehicles are provided below.

Truck Fleets. In 1970, 203,044 trucks operated within the Chicago SMSA [Ref. 19]. These trucks operated internally, i.e., both origins and destinations were in the Chicago SMSA, and had a 74.1% daily utilization rate [Ref. 19]. Therefore, an estimated 203,044 • 0.741 = 150,456 internal truck trips were made daily. An estimated 44,180 truck trips were made daily in the Chicago SMSA and Lake and Porter counties in Indiana with either the origin or destination not in this eight-county area; these are defined as external truck trips [Ref. 19]. Since 92.4% of the internal trucks operated in the Illinois portion of the eight-county region, 92.4% of the external truck trips

Table 9.2. Fleet Vehicles in the Chicago SMSA Subject to Action 7

Type of Fleet	Number of Vehicles
Trucks	63,199
Automobiles	
Northern Illinois Gas	528
Peoples Gas	298
Commonwealth Edison	1,069
Taxis/Livery	6,928
Other	8,823
TOTAL	80,845

are assumed to have originated or terminated in the Illinois portion of the region. Assuming one truck was used per external truck trip, then approximately $150{,}456 + 44{,}180 \cdot 0.924 = 191{,}278$ trucks operated daily in the Chicago SMSA in 1970. Since vehicle miles traveled did not change significantly between 1970 and 1974, 191,278 trucks are assumed to have operated each day in the Chicago SMSA in 1974.

However, not all of these trucks are subject to the provisions of Action 7. Government trucks must be subtracted from this total. A profile of urban truck Vmt for commercial and government trucks is shown in Table 9.3. The daily Vmt totals estimated in Appendix E for light gasoline and all heavy trucks are 2,986,120 and 4,755,866 miles, respectively. Therefore, about $(3.7 \cdot 2{,}986{,}120 + 7.4 \cdot 4{,}755{,}866)/7{,}741{,}986 = 5.97\%$ of the truck Vmt is from

Table 9.3. Government and Nongovernment Truck Vmt

Classification	% of Truck Vmt[a] GVW < 10,000 lbs.	% of Truck Vmt[a] GVW ≥ 10,000 lbs.
Nongovernment Trucks	96.3	92.6
Government Trucks	3.7	7.4
TOTAL	100.0	100.0

[a]These percentages are based on Vmt data obtained for 11 cities, excluding Chicago, given in Ref. 9.

government trucks. If this percentage is applicable to the Chicago SMSA, and government trucks' travel patterns are similar to commercial trucks', then the number of government trucks operating in the Chicago SMSA is 191,278 • 0.0597 = 11,419. The number of nongovernment trucks is 191,278 - 11,419 = 179,859.

Trucks in fleets of less than three vehicles are exempt from Action 7. According to the 1972 *Census of Transportation* [Ref. 4] 398,000 of the 695,000 nongovernment trucks registered in Illinois are in fleets of one truck, and 169,000 are in fleets of two to five trucks. If the number of trucks in fleets of two to five trucks is proportionally distributed, then $100 \cdot [2/(2 + 3 + 4 + 5)] = 14.29\%$ or 24,143 of the 169,000 trucks are in fleets of two trucks. Therefore, $100 \cdot (398{,}000 + 24{,}143)/695{,}000 = 60.74\%$ of the nongovernment trucks in Illinois are exempt from Action 7 since they are not in fleets of three or more trucks. Assuming that this percentage applies to the nongovernment fleets that operate in the Chicago SMSA, then $179{,}859 \cdot (1 - 0.6074) = 70{,}613$ nongovernment trucks in fleets of three or more vehicles operate daily in the Chicago SMSA.

Some of these trucks transport groceries, pharmaceuticals, or essential fuels and would also be exempt from Action 7. Listed in Table 9.4 are commodities assumed to be grocery or pharmaceutical goods and the delivered tonnages of each commodity for internal truck trips in the eight-county CATS study area. The external commodity delivery breakdown by two-digit Standard Commodity Classification (SCC) code for commodity groups containing grocery and pharmaceutical goods is shown in Table 9.5. Since the two-digit commodity groups are broad breakdowns, the amount of goods in each group which is actually exempt from the regulation must be estimated. Based on the data of Table 9.4 and other commodity data from Ref. 19, the fractions of internal delivered tons that are grocery or pharmaceutical goods for the SCC groups of Table 9.5 are calculated and are shown in Table 9.6. Assuming that the exempt portion of external deliveries of SCC codes 01, 09, 20, and 28 is equal to the exempt portion of internal deliveries in these groups, the following estimate of daily external exempt delivered tonnages is made: $(20{,}300 \cdot 1.0) + (190 \cdot 1.0) + (52{,}230 \cdot 0.76) + (15{,}870 \cdot 0.03) = 60{,}661$. Adding the external and internal estimates, 146,305 tons of exempt goods are delivered daily out of a total delivered tonnage of 1,480,433 [Ref. 19]. It is estimated that 9.86% of delivered tonnage consists of groceries and pharmaceuticals.

Table 9.4. Grocery and Pharmaceutical Goods

Commodity[a] and Standard Commodity Classification Code	Internal Delivery in Eight-County Area (tons/day)
Field Crops (011)	1,377
Fresh Fruit (012)	1,105
Fresh Vegetables (013)	4,688
Livestock (014)	3,132
Livestock Products (015)	71
Poultry and Poultry Products (016)	442
Grain (017)	12,639
Miscellaneous Farm Products (019)	5,247
Fresh Fish and Marine Products (091)	38
Meat Products (201)	13,360
Dairy Products (202)	11,112
Grain Mill Products (204)	3,244
Bakery Products (205)	6,377
Sugar (206)	3,789
Confectionary Products (207)	879
Miscellaneous Food Products (209)	17,183
Drugs (283)	961
TOTAL	85,644

Source: Ref. 19.

[a]All commodity groups are considered grocery goods except for drugs which are considered pharmaceutical goods.

Table 9.5. External Exempt Commodity Groups

Commodity and Two-Digit SCC Code	External Delivery in Eight-County Area (tons/day)
Farm Products (01)	20,300
Fish and Marine (09)	190
Food and Kindred (20)	52,230
Chemical Products (28)	15,870

Source: Ref. 19.

Table 9.6. Estimated Exempt Component

Commodity and Two-Digit SCC Code	Fraction of Internal Delivered Tonnage That is Exempt
Farm Products (01)	1.0
Fish and Marine (09)	1.0
Food and Kindred (20)	0.76
Chemical Products (28)	0.03

In the winter,the transporting of heating fuel might be considered essential. However, during the summer months (i.e., the ozone season) the number of trucks transporting essential fuels is assumed to be insignificant. Therefore, an estimated 9.86% of the trucks operating in the Chicago SMSA are exempt from Action 7 because they transport grocery, pharmaceutical, or essential fuel products. Assuming this percentage is applicable to all truck classes, then 70,613•(1 - 0.0986) = 63,651 nongovernment trucks operate each day in the Chicago SMSA that are in fleets of three or more vehicles and do not transport grocery, pharmaceutical, or essential fuel products.

Some of these trucks are in utility fleets and are used for emergency purposes. Northern Illinois Gas has 1,000 trucks, of which 85% operate in the Chicago SMSA and 4.5% are normally used for emergency purposes [Ref. 2]. Peoples Gas, Light, and Coke Company operates 646 trucks in the Chicago SMSA, of which 1.5% are normally used for emergency purposes [Ref. 10]. Commonwealth Edison Company operates 1,980 trucks of which 10% are normally used for emergencies [Ref. 18]. It is assumed that 90% of Commonwealth Edison trucks operate in the Chicago SMSA. No data were available on the Illinois Bell Telephone fleet operations or other small truck fleets that may be used for emergencies. The number of trucks execpt from these unknown fleets is assumed equal to that exempt from the fleets listed above.

Therefore, the total number of fleet trucks exempt from Action 7 because of emergency use is estimated to be: 2•[(1,000 • 0.85 • 0.045) + (646 • 0.015) + (1,980 • 0.9 • 0.1)] = 452. The total number of trucks subject to the provisions of Action 7 is estimated to be: 63,651 - 452 = 63,199.

Automobile Fleets. Northern Illinos Gas has 650 automobiles; 85% operate in the Chicago SMSA and 4.5% are used for emergency purposes [Ref. 2]. From these data approximately $650 \cdot 0.85 \cdot (1 - 0.045) = 528$ cars are affected by Action 7.

Peoples Gas, Light, and Coke Company has 299 automobiles, all of which operate in the Chicago SMSA; only 0.5% are normally used for emergencies [Ref. 10]. Therefore, $299 \cdot (1 - 0.005) = 298$ of these cars are subject to Action 7.

Of Commonwealth Edison's 1,320 automobiles, approximately 10% are used for emergencies [Ref. 18]. It is assumed that 90% of Commonwealth Edison's automobiles operate in the Chicago SMSA. Therefore, $1{,}320 \cdot 0.90 \cdot (1 - 0.10) = 1{,}069$ Commonwealth Edison cars are subject to Action 7.

In 1975, 7,995 vehicles in the Chicago SMSA had taxi, livery, and ambulance licenses [Ref. 13]; this figure is assumed applicable to 1974. Only 563 vehicles are registered as ambulances in Illinois [Ref. 1]. Assuming the number of ambulances is proportional to population, then $563 \cdot 0.628 = 354$ ambulances operate in the Chicago SMSA.* Therefore, an estimated $7{,}995 - 354 = 7{,}641$ taxi and livery vehicles operate in the Chicago SMSA.

In Chicago, there are about 4,600 taxis and 327 limousines [Ref. 14], i.e., 93.3% of the taxi/livery vehicles are taxis.** Assuming this percentage applies to all the taxi/livery vehicles in the Chicago area implies that there are 7,134 taxis and 507 limousines. All the limousines are assumed to be in fleets of more than two vehicles. However, some taxis are owner-operated. Since, in Chicago, about 80% of the cabs are operated by two companies, at most 20% of the Chicago cabs are owner-operated. It is assumed that 90% of the cabs are affected by Action 7. Therefore, a total of $0.9 \cdot 7{,}134 + 507 = 6{,}928$ taxi/livery vehicles are affected by Action 7.

Information on other automobile fleets could not be found (e.g., rental cars and small business fleets). To account for these vehicles, an estimate equal to the sum of the known automobile fleet vehicles is used, i.e., $8{,}823 = 528 + 298 + 1{,}069 + 6{,}928$.

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*In 1970, about 62.8% of Illinois' citizens resided in the Chicago SMSA.

**Livery vehicles are assumed to be comprised of limousines, including both automobile and bus-type limousines.

The sum of the truck and automobile fleet vehicles subject to Action 7 is $\tilde{N}$ = 80,845, as indicated in Table 9.2. The value of $\tilde{W}$ is $1,416 as before. If α is set equal to 10 (i.e., it takes 10 minutes on the average to reschedule a vehicle or worker) then the rescheduling costs would be those shown in Table 9.1.

Shut-Down/Start-Up Cost

The cost of shutting down and starting up automobile fleets would be small since it only involves keeping vehicles in already available lots or garages.* Therefore, only truck fleets are assumed to have significant shut-down and start-up costs. The regulation states that on the first day, vehicles cannot be dispatched nor operated on the second day. This implies that vehicles already dispatched on the first day may continue to operate. Therefore, trucks that operate within a day's journey of the affected area will be able to return to their home base where they are parked or garaged. In this case, no shut-down or start-up cost will be incurred.

For trucks making interstate trips, it is possible that a truck, or its cargo, may have to be stored away from its home base at an additional cost. Furthermore, both vehicles and drivers may be out of position, resulting in a cost to reposition them.

However, information on the potential impacts and resulting costs of keeping interstate truck traffic from entering or leaving the affected area could not be obtained. Since the shut-down and start-up problems facing the trucking industry are similar to those facing the airline industry (discussed in Chapter 21), the shut-down/start-up cost per interstate truck trip is assumed to be proportional to the shut-down/start-up cost per airplane segment.**

The shut-down/start-up cost for the airlines is approximately $250 per segment (see Sec. 21.1). Therefore, the shut-down/start-up cost is:

*If the vehicles were used continuously over a 24-hour period, seven days a week, then parking areas may have to be rented during an episode. However, none of the automobile fleets considered in this analysis fall into this category.

**A segment is either an arrival or departure.

$$C' = 250 \cdot \beta \cdot N' \tag{9.4}$$

where:

$C' \equiv$ the shut-down/start-up cost,

$N' \equiv$ the number of vehicles affected, and

$\beta \equiv$ the proportionality factor between truck and airline shut-down/start-up costs.

In the six-county Chicago SMSA and Lake and Porter counties in Indiana, 44,180 truck trips are made with origins or destinations outside the eight-county area, i.e., external trips [Ref. 19]. Since 92.4% of the trucks making trips with both origins and destinations in the eight-county area, i.e., internal trips, are registered in Illinois [Ref. 19], it is assumed that $40{,}822 = 44{,}180 \cdot 0.924$ of the external trips have origins or destinations in the Chicago SMSA. Of those only 33.06%* are affected by Action 7. If it is assumed that half of these are interstate trucks or haul freight long distances (i.e., incur shut-down and start-up costs) then $N' = 40{,}822 \cdot 0.3306/2 = 6{,}748$. Setting $\beta = 0.10$ results in the shut-down/start-up costs given in Table 9.1. This cost is independent of the length of the episode.

Cost of Delayed Deliveries

A delay in the delivery of an item could result in delays in production and consumption or only affect inventory levels. Since a detailed analysis of delays in deliveries would require knowledge of delivery schedules, inventory stocks, production schedules, and the like, and such information is not readily available, delays in deliveries are assumed to result only in delays in consumption. Using this assumption the cost of delaying deliveries for an n-day episode would be:

$$\underline{C} = \lambda \cdot \sum_{t=1}^{n} D \cdot P_t = \lambda \cdot D \cdot \sum_{t=1}^{n} P_t \tag{9.5}$$

where:

$\underline{C} \equiv$ the delay of deliveries cost,

$D \equiv$ the value of daily consumption in retail stores affected by Action 7,

$P_t \equiv$ a delay factor, and

$\lambda \equiv$ the fraction of daily consumption that is delayed.

*Of the 191,278 trucks that operate in the Chicago SMSA (non-through traffic) only 63,199, or 33%, are subject to the provisions of Action 7.

An example will help to clarify the interpretation of Eq. 9.5. Consider a three-day episode. The delayed purchases during the first day are assumed to be delayed a minimum of three days and a maximum of 10 days. They are delayed at least three days because the episode is three days long. It is assumed that these purchases will be made within one week after the episode is over, i.e., the maximum delay is 3 + 7 = 10 days. The purchases delayed during the second day of the episode have only a two-day minimum delay, and are also assumed to be made within a week after the episode ends. Similarly, the purchases on the last day of the episode will have a minimum delay of only one day and a maximum delay of eight days. Table 9.7 summarizes these assumptions and provides the corresponding delay factors, P_t.

Only retail stores are assumed to be affected by delays in deliveries because service, financial, and other consumer goods are less dependent on trucking. Since grocery and pharmaceutical products can be shipped, retail sales of these products probably will not be delayed. In 1972, \$17,231 million in retail sales was made in the Chicago area [Ref. 3]. Of this, \$3,318 million was in food stores and \$709 million in drug stores. Therefore, in 1972 dollars, $D = \$(17{,}231 - 3{,}318 - 709)\cdot 10^6/365 = \$36.18$ million. In 1974 dollars this is \$42.65 million (see Table A.6 for consumer price indices used to convert from 1972 to 1974 dollars).

Table 9.7. Assumed Minimum and Maximum Delays and Corresponding Delay Cost Factors

t	Minimum Delay (days)	Maximum Delay (days)	Delay Factor[a] P_t
1	1	8	0.000913
2	2	9	0.001174
3	3	10	0.001435
4	4	11	0.001695
5	5	12	0.001956

[a] A 10% discount rate is assumed; see Table A.7 and discussion in Sec. 2.1.

Since there is no information on the fraction of daily consumption that might be delayed, it is assumed $\lambda = 0.5$, a mid-range estimate. Substituting these values of D, P_t, and λ into Eq. 9.5 results in the delay of delivery costs shown in Table 9.1.

Overtime Cost

Assuming that all man-hours lost during an episode for truck and utility fleets must be made up using overtime labor results in an overtime cost for an n-episode of:

$$\hat{C} = 0.5\cdot\hat{W}\cdot H\cdot n \quad (9.6)$$

where:

$\hat{C}$ ≡ the overtime costs,

$\hat{W}$ ≡ the average hourly wage rate of fleet vehicle drivers,

H ≡ the number of man-hours lost due to an episode, and

The constant 0.5 reflects the assumption that on the average, the overtime rate is 1.5 times the normal wage rate.

The value of $\hat{W}$ is assumed to be \$5/hour.* If eight man-hours are assumed lost per day per vehicle affected, then $H = 8 \cdot [80{,}845 - (6{,}928 \cdot 2)] = 535{,}912$. (It is assumed there are 6,928 • 2 non-utility fleet automobiles). Substituting these values of $\hat{W}$ and H into Eq. 9.6 yields the overtime costs provided in Table 19.1.

Cost of Canceled or Delayed Trips

No information is available on the trip purposes of persons using rental cars. Many of these people are assumed to be on vacation or business trips, many of which, without the use of a rental car, would have to be canceled or delayed.

Since no data were available to estimate the cost of delaying or canceling these trips, the cost to rental car customers who alter trip plans is assumed to be the same as the cost to airline customers who alter trip plans due to Action 19 (See Sec. 21.1).** This is equivalent to assuming that 4,045 rental car customers cancel their trips and 16,181 delay their trips each day of an episode, and that the expenditures made on these trips are similar to those made by airplane customers.

The costs of canceled and delayed trips in Table 9.1 are estimated using the above assumptions.

Cost of Alternatives to Taxi/Livery Services

People who would normally use taxi/livery services have a number of potential substitutes to the use of these services. For example, they could

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*This is about the average hourly wage of manufacturing production workers in 1974.

**For Action 19 some airline passengers are assumed to be detained away from home. This is not assumed to be likely for rental car customers.

walk, take mass transit, use a personal car, or delay or cancel the trip. It seems that the use of the personal automobile as an option is unlikely. As Ronald J. Sutherland argued in testimony before the Illinois Pollution Control Board:

> Although the automobile appears to be the closest substitute for a taxicab, I do not anticipate an increase in auto use. First, if a person had access to an automobile he would not select the higher cost taxi service. Secondly, many of those who use taxicabs do not drive. Thirdly, the closure of large parking lots and the emergency atmosphere which will prevail during an episode will serve as disincentives to automobile travel. [Ref. 16].

The first two points made by Dr. Sutherland are supported by statistics on taxicab riders [Ref. 8]. In addition, relatively few trips are likely to be canceled since most taxicab rides are for home and work trips. It is assumed no trips will be canceled, although some may be delayed. Therefore, the alternatives to taxi/livery services considered here are the use of mass transit, walking, or the delay of trips.

The cost of using an alternative mode of transportation, i.e., mass transit or walking, for an n-day episode is:

$$C'' = N''\bullet d\bullet P\bullet n \qquad (9.7)$$

where:

$C'' \equiv$ the alternative mode of transportation cost,

$N'' \equiv$ the average number of persons that use taxi/livery services daily,

$d \equiv$ the incremental cost of using a substitute mode of travel, and

$P \equiv$ the fraction of taxi/livery customers that uses an alternative mode of travel.

Based on nationwide surveys of taxi operations, the average cost per taxi trip ranges from \$2.90 to \$3.20 and the average occupancy is between 1.3 and 1.6 passengers per trip [Ref. 8]. These statistics tend to be consistent regardless of the size of the operation or its location. The cost figures are for 1970. The average taxi ride in 1974 dollars cost* [(2.90

*See Table A.6 for consumer price index.

+ 3.20)/2]•[147.7/116.3] = $3.87 and the average occupancy was (1.3 + 1.6)/2 = 1.45 passengers/trip. Therefore, the average cost per person for a taxi ride is estimated to be $3.87/1.45 = $2.67.

It is assumed that most of the livery service is to O'Hare International Airport. From downtown Chicago the cost of a limousine to O'Hare is $3.15, while from the far western suburbs it is $12.60 [Ref. 7]. Assuming the number of persons using livery services in each county is proportional to population in the county and that persons in Cook County have an average livery cost of $3.15 and those in the other five counties have an average livery cost of $12.60, then the average livery cost per person in 1976 is 0.787 • 3.15 + 0.213 • 12.60 = $5.16.* In 1974 dollars this cost is $4.52.

The Chicago Area Transportation Study estimates that 156,849 taxi trips are made each day in the Chicago SMSA [Ref. 15]. With an average occupancy rate of 1.45, an estimated 227,431 persons use taxis each day. Since it is assumed that 10% of these are not in fleets, it is estimated that 0.90 • 227,431 = 204,688 persons that use taxis are affected by the regulation. If the number of persons using taxis and limousines is proportional to the number of vehicles, then approximately 204,688 • 507/6,421 = 16,162 persons use limousines each day in the Chicago SMSA. Therefore, N'' = 204,688 + 16,162 = 220,850 persons.

The average cost per person for taxi/livery services each day is [(204,688 • 2.67) + (16,162 • 4.52)]/220,850 = $2.81. The average mass transit cost in 1974 is assumed to be $0.44** Therefore, the mass transit fare is 2.81 - 0.44 = $2.37/person less expensive than using taxi/livery services. However, the time (inconvenience, safety, etc.) cost for mass transit is greater. Since a high percentage of taxicab riders are in both the high- and low-income groups [Ref. 12] and many homemakers use taxis [Ref. 8], a reasonable value of time is $5.00/hr, which is about the average wage of production workers in the Chicago SMSA in 1974 and is about the average between a low- and high-wage earner. Assuming a mass-transit trip takes, on the average, δ minutes longer than a taxi or limousine ride [δ is the assumed value

*In 1970, 78.7% of the people in the Chicago SMSA lived in Cook County; see Table A.1.

**This is a cost of $0.50 adjusted to 1974 dollars.

of the incremental time between the use of taxi/livery services and mass transit (or walking)], then $d = 5 \cdot \delta/60 - 2.37$. Setting $\delta = 40$ provides an estimate of $d = 0.963$.*

Since 51% of the taxi trips are in the Chicago Central Business District [Ref. 12], many taxi and limousine trips are made to O'Hare [Ref. 12], and public transit is an available option in these places, the value of P is assumed to be greater than 0.51. About 56% of the taxi trips are work or home trips, which also implies that P is relatively large [Ref. 8]. Therefore, P is set equal to 0.75.

Substituting these values of N'', d, and P into Eq. 9.7 results in an estimated cost of using an alternative mode of transportation of:

$$C'' = 220{,}850 \cdot 0.963 \cdot 0.75 \cdot n = \$159{,}509 \cdot n \qquad (9.8)$$

For the individuals who delay their trips, the cost is calculated using Eq. 9.5 with D being defined as the expenditure made for taxi/livery services and expenditures at the final destination, and the value of $\lambda = (1 - P) = 0.25$. The expenditure made for taxi/livery services is \$2.81/person; it is assumed the delayed expenditure at the final destination is \$5.00/person. Therefore, for the 220,850 persons affected: $D = 220{,}850 \cdot (2.81 + 5.00) = \$1{,}724{,}839/\text{day}$. Substituting these values of D and λ along with the P_t values in Table 9.7 into Eq. 9.5 yields delay costs of \$394, \$900, \$1,519, \$2,245, and \$3,094 for episodes of one to five days, respectively.

Summing the alternative mode of travel and the delay of trip cost gives the alternative-to-taxi/livery-service costs in Table 9.1.

Cost of Diversion of Through Traffic

The cost for an n-day episode of diverting through fleet traffic is estimated as follows:

$$\ddot{C} = (V \cdot \ddot{P} \cdot M + \ddot{N} \cdot \ddot{W} \cdot \ddot{H}) \cdot n \qquad (9.9)$$

*This value of δ includes time to and from the mass-transit station, differential wait time and differential travel times. Note that although no fare would occur for the walking alternative, the time of travel would increase more. It is assumed d is applicable to both options. It is possible that many of these people will use the non-fleet cabs still operating. The differential cost in this case is the added waiting time required because there are fewer cabs.

where:

$\ddot{C}$ ≡ the cost of diverting through traffic,

V ≡ the daily vehicle miles traveled in the study area by through traffic,

$\ddot{P}$ ≡ the fractional increase in vehicle miles traveled by through traffic if it is diverted,

M ≡ the cost per mile of using a motor vehicle,

$\ddot{N}$ ≡ the number of trips diverted,

$\ddot{W}$ ≡ the hourly wage rate of the driver, and

$\ddot{H}$ ≡ the increased travel time caused by diverting traffic.

In 1970, 8,290 truck trips were made through the Chicago SMSA and Lake and Porter counties in Indiana [Ref. 19]. These trucks traveled 626,920 miles in the study area. As before, 92.4% of this traffic is assumed to occur in the Illinois portion of the eight-county region. Furthermore, it is assumed that (63,199/191,278)•100 = 33.06% of these trucks are subject to the provisions of Action 7.* Therefore, an estimated 8,290 • 0.924 • 0.3306 = 2,532 through truck trips are affected by Action 7 and these trucks travel 626,920 • 0.924 • 0.3306 = 191,508 miles in the Chicago SMSA, i.e., $\ddot{N}$ = 2,532 and V = 191,508.

The percentage increase in vehicle miles traveled by through fleet trucks is estimated by calculating the airline distance around and through the study area in a north-south direction. The difference in these distances is 185 - 95 = 90 miles. The fractional increase in the travel distance is: P = (185 - 95)/95 = 0.947.**

The value of M is assumed to be \$0.13/mile•(13.6/7.21) = \$0.245/mile. The constant \$0.13 is the tax allowance for automobile operations provided by the IRS adjusted to 1974 dollars. The factors 13.6 and 7.21 are the average miles per gallon for automobiles and trucks, respectively [Ref. 5]. The value of $\ddot{W}$ is assumed to be \$5.00/hr.†

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*Of the 191,278 trucks that operate in the Chicago SMSA (non-through traffic trucks) only 63,199 are subject to the provisions of Action 7.

**Airline distance could be multiplied by any constant to obtain actual travel distance and the value of $\ddot{P}$ will not change.

†\$5.00/hr is about the average wage rate of production workers in the Chicago SMSA in 1974.

The value of $\ddot{H}$ is calculated by assuming that the trucks normally traveling through the area use expressways during off-peak periods and travel at an average speed of 49.9 mph. If diverted, they are assumed to use rural roads and travel at an assumed average off-peak speed of 40.0 mph. Therefore: $\ddot{H} = (185/40.0) - (95/49.9) = 2.72$ hrs.

Substituting the values of V, $\ddot{P}$, M, $\ddot{N}$, $\ddot{W}$, and $\ddot{H}$ into Eq. 9.9 yields the estimated costs of diverting traffic provided in Table 9.1

9.2 EMISSION REDUCTION EFFECTS OF ACTION 7

Vehicular Sources

The motor vehicle emission reduction due to Action 7 is estimated with the following equation:

$$R_p = A_p + B_p + G_p \tag{9.10}$$

where:

$R_p \equiv$ emission reduction of pollutant p due to the action (tons/day);

$p \equiv$ pollutant: 1 = hydrocarbons, 2 = nitrogen oxides;

$A_p \equiv$ emission reduction of pollutant p due to curtailing traffic (tons/day);

$B_p \equiv$ emission change of pollutant p due to an increase in the average speed of vehicles remaining in operation (tons/day); and

$G_p \equiv$ evaporative emission reduction due to reduced sales of gasoline.*

The variable A_p is estimated using the following equation:

$$A_p = \sum_{j=1}^{4} \sum_{i=1}^{5} (V_i - V_i^e) \cdot f_{ij} \cdot E_{pi}(S_j)/907{,}184 \tag{9.11}$$

where:

$j \equiv$ traffic segment: 1 = expressway peak, 2 = expressway off-peak, 3 = arterial peak, and 4 = arterial off-peak;

$i \equiv$ vehicle class: 1 = low-mileage autos, 2 = high-mileage autos, 3 = light gasoline-powered trucks, 4 = heavy gasoline-powered trucks, and 5 = heavy diesel-powered trucks;

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*These evaporative emissions are allocated to motor vehicle emission reductions because they are a direct consequence of reduced vehicle miles traveled.

V_i ≡ Vmt from vehicles in class i and in fleets of three or more vehicles (miles/day);

V_i^e ≡ Vmt from vehicles in class i and in fleets of three or more vehicles that are exempt from the action (miles/day);

f_{ij} ≡ fraction of class i vehicle Vmt apportioned to traffic segment j;

$E_{pi}(S_j)$ ≡ emission factor for pollutant p from vehicles in class i, traveling at average speed S_j (grams/mile); and

The constant 1/907,184 converts grams to tons.

The variable B_p is estimated using the following equation:

$$B_p = \sum_{j=1,3} \sum_{i=1}^{9} (T_{ij} - \overline{V}_{ij}) \cdot [E_{pi}(S_j) - E_{pi}(S_j^*)]/907{,}184 \qquad (9.12)$$

where:

T_{ij} ≡ Vmt, before the action, of vehicles in class i during traffic segment j;

$\overline{V}_{ij}$ ≡ Vmt, from vehicles in class i and in fleets of more than two vehicles, curtailed by the action during traffic segment j: note that $\overline{V}_{ij} = (V_i - V_i^e) \cdot f_{ij}$;

$E_{pi}(S_j^*)$ ≡ emission factor for vehicles of class i of pollutant p after the action at average speed S_j^*;

j is summed over the two peak traffic segments (j=1 ≡ expressway peak, j=3 ≡ arterial peak);

i is summed over all nine vehicle classes (see Appendix E); and

$E_{pi}(S_j)$ and the constant 1/907,184 are defined as in Eq. 9.11.

The Vmt data pertaining to the groups of vehicles affected by the action are not readily available; the procedure for estimating the Vmt curtailed in each vehicle class is described in the following sections.

Automobile Fleet Vmt. Automobiles in fleets of three or more vehicles include taxi/livery, utility, and commercial fleets. In Appendix E, taxi Vmt is estimated to be 872,080 miles/day and utility and commercial fleet auto Vmt is estimated at 149,086 miles/day.

Nongovernment Truck Fleet Vmt. The truck Vmt data presented in Appendix E include both government and commercial trucks. Since government vehicles are not defined as fleet vehicles in the regulation, the Vmt component due to commercial trucks must be estimated. A profile of urban

truck Vmt for commercial and government trucks was shown in Table 9.3. The category in Table 9.3 labeled "less than 10,000 lbs. GVW" is comparable to the light gasoline truck class used in the study. The daily Vmt totals obtained in Appendix E for light gasoline, heavy gasoline, and heavy diesel trucks were 2,986,120 miles, 2,924,026 miles, and 1,831,840 miles, respectively. These Vmt estimates are multiplied by the data in Table 9.3* to obtain Vmt figures for nongovernment trucks. The daily estimates are 2,875,634 miles, 2,707,648 miles, and 1,696,284 miles, respectively.

Next, the portion of the nongovernment truck Vmt due to vehicles in fleets of three or more is determined. Table 9.8 contains fleet truck Vmt data for Illinois. The pickup and panel truck category in the table corresponds to the light gasoline truck category. Assuming that fleets of two to five vehicles account for proportional total mileage, pickups and panel trucks in fleets of three or more vehicles acccount for 23.93% of all pickup and panel Vmt. Using the same assumption, 82.10% of the Vmt for other trucks is due to trucks in fleets of three or more vehicles. Applying the state data to the SMSA, the daily Vmt of nongovernment trucks in fleets of three or more vehicles is estimated as: 2,875,634 • 0.2393 = 688,139 miles/day for light gasoline trucks; 2,707,648 • 0.8216 = 2,224,604 miles/day for heavy gasoline trucks; and 1,696,284 • 0.8216 = 1,393,667 miles/day for heavy diesel trucks.

Vmt from Exempt Fleet Vehicles. For lack of more information, it is assumed that the percentage of tonnage of grocery and pharmaceutical goods is equal to the percentage of Vmt for the delivery of these goods. Previously

Table 9.8. Illinois Truck Vmt Breakdown by Number of Vehicles in Fleet

	Annual Vmt (10^6 miles)	
Fleet Size	Pickups and Panels	Other Trucks
1	3,218	440
2-5	702	1,116
>5	442	1,804
TOTAL	4,362	3,360

Source: Ref. 4.

*It is assumed these data are applicable to the Chicago SMSA.

it was estimated that 9.86% of delivered tonnage in the Chicago SMSA consists of grocery (food) and pharmaceutical products. Applying this percentage to all truck classes in fleets of more than two trucks gives additional exempt Vmt of 688,139 • 0.0986 = 67,851 miles/day for light gasoline trucks; 2,224,604 • 0.0986 = 219,346 miles/day for heavy gasoline trucks; and 1,393,667 • 0.0986 = 137,416 miles/day for diesel trucks. It is assumed that the amount of grocery and pharmaceutical goods delivered by automobile fleets is insignificant.

While in the winter, the amount of heating fuel transported which would be termed essential would be a significant quantity, this would not be the case in the summer. Although situations exist in which fuel deliveries can be hypothesized, the traffic component due to these deliveries would be very small in the summer. In addition, ambulance travel will not be curtailed.

Other essential travel is by emergency utility vehicles. In Appendix E, utility and commercial fleet Vmt is estimated at 149,086 miles/day. Based on a weighted average of the data obtained from utilities, approximately 7.47% of utility auto usage is for emergency purposes. Emergency travel Vmt is thus estimated at 11,137 miles/day. Also, from utility data, it is estimated that truck emergency Vmt is 16,484 miles/day, assumed entirely due to light gasoline trucks. In addition, not all of the taxi/livery Vmt will be curtailed. Assuming that 90% of taxis are in fleets of three or more vehicles, and all limousines are, and assuming that taxis and limousines travel the same annual mileage per vehicle, then 92.9% of the taxi/livery Vmt will be curtailed. The remaining 872,080•(1 - 0.929) = 61,918 Vmt will be exempt.

The information on fleet vehicle curtailment is summarized in Table 9.9.

Vmt Estimates of Fleet Vehicles by Traffic Segment. To calculate emission reductions from curtailing fleet vehicles, the Vmt estimates are broken down by traffic segment. The Vmt figures in Table 9.9 are divided among the four traffic segments in the same proportions discussed in Appendix E; the Vmt reductions by traffic segment appear in Table 9.10.

Emission Reduction Estimates for Vehicular Sources. The emission reduction due to the fleet Vmt curtailment is estimated by substituting into Eq. 9.11 the HC and NO_x emission factors in Tables E.4 and E.5 $[E_{pi}(S_j)]$ and

Table 9.9. Summary of Fleet Vmt Curtailments

Type of Fleet	Fleet Vmt (V_i)	Vmt Exempt from Curtailment (V_i^e)	Vmt Curtailed ($V_i - V_i^e$)
Utility & Commercial Auto	149,086	11,137	137,949
Taxi/Livery	872,080	61,918	810,162
Light Gas Truck	688,139	67,851	620,288
Heavy Gas Truck	2,224,604	219,346	2,005,258
Heavy Diesel Truck	1,393,667	137,416	1,256,251
TOTAL	5,328,004	497,668	4,829,908

Table 9.10. Vmt Reduction by Traffic Segment

Type of Fleet	Daily Vmt Reduction, $\overline{V}_{ij}$ (miles/day)			
	Expressway Peak	Expressway Off-Peak	Arterial Peak	Arterial Off-Peak
Utility & Commercial Auto	10,346	25,383	31,590	70,630
Taxi/Livery	60,762	149,070	185,527	414,803
Light Gas Truck	46,522	114,133	133,982	325,651
Heavy Gas Truck	150,394	368,967	433,136	1,052,760
Heavy Diesel Truck	94,219	231,150	271,350	659,532
TOTAL	362,243	888,703	1,055,585	2,523,376

the Vmt reduction estimates ($\overline{V}_{ij}$) in Table 9.10. From this procedure, the reduction in HC emissions due to fleet vehicle curtailment is estimated to be 78.7 tons/day; the reduction in NO_x emissions is estimated at 64.7 tons/day.

Because of the significant reduction of peak hour traffic, an increase in the average speed of the remaining peak hour traffic occurs. The change in vehicle emissions due to the speed increase is calculated using the procedure described in Appendix F. First, Vmt reductions are used to establish average traffic flow rates. Speed increases are calculated from the flow rates. Revised emission factors are calculated for the new speeds and applied to the reduced Vmt estimates to obtain total emissions.

The total Vmt reduction of arterial peak traffic, from Table 9.10, is estimated at 1,055,585 miles/day. The remaining arterial peak Vmt is then

21,393,000 - 1,055,585 = 20,337,415 miles/day for an average flow rate of 20,337,415/5 = 4,067,483 Vmt/hour. Employing the arterial speed adjustment equation from Appendix F, it is estimated that average arterial speed during the peak period will increase from 11.9 to 13.3 mph. Similarly, expressway-peak Vmt declines by 362,243, from 7,451,000 to 7,088,757 miles/day. The expressway flow rate is then 1,417,751 Vmt/hour. Employing the expressway speed adjustment equation from Appendix F, the average speed of the remaining traffic is estimated to be 44.4 mph.

The emission factors for all vehicle classes at the increased peak speeds were calculated and used to estimate the emission change due to the speed increase from Eq. 9.12. The results of these calculations are shown in Table 9.11.

In Table 9.11, it is shown that the speed increase results in 12.9 tons/day decline in HC emissions, due mostly to the increase in arterial traffic speed from 11.9 to 13.3 mph. As shown in Fig. E.1, the HC emission rate of most vehicles is very sensitive at low average speeds.

From Table 9.11 the total reduction of NO_x is estimated to be 1.67 tons/day. Expressway traffic actually increases NO_x production, as would be expected from the shape of the NO_x emission rate vs. speed/curve, Fig. E.2.

The evaporative hydrocarbon emission reduction, G_1, is estimated in Appendix G to be 4.68 tons/day. The value of G_2 is equal to zero. Therefore, the total motor vehicle emission reduction is equal to:

Table 9.11. Reduction of Total Vehicle Emissions Due to Speed Increase

	Emission Reduction (tons/day)	
Peak Traffic Segment	HC	NO_x
Expressway	0.166	-0.177[a]
Arterial	12.7	1.85
TOTAL	12.9	1.67

[a]A minus sign indicates an increase in emissions.

$R_1 = 78.7 + 12.9 + 4.68 = 96.3$ tons HC/day, and

$R_2 = 64.7 + 1.67 = 66.4$ tons NO_x/day.

Evaporative Hydrocarbon Emission Reductions

Because gasoline tank trucks are assumed to be in fleets of more than two vehicles, they are affected by Action 7. Therefore, the loading and unloading of gasoline tank trucks is assumed to be curtailed. The resulting reduction in hydrocarbon emissions is estimated as follows:

$$\overline{A} = (Q_u + Q_e - Q_m)\cdot E_\ell + Q_u\cdot(E_u + E_g) \qquad (9.13)$$

where:

$\overline{A}$ ≡ emission reduction of hydrocarbons due to the curtailment of loading and unloading gasoline tank trucks (tons HC/day),

Q_u ≡ the quantity of gasoline unloaded at gasoline stations in the SMSA (gal./day),

Q_e ≡ the quantity of gasoline exported from the study area by truck (gal./day),

Q_m ≡ the quantity of gasoline imported to the study area by truck (gal./day),

E_ℓ ≡ the emission rate of hydrocarbons from the loading of tank trucks (tons HC/gal.),

E_u ≡ the emission rate of hydrocarbons from the unloading of tank trucks (tons HC/gal.), and

E_g ≡ the emission rate of hydrocarbons from the loading of underground tanks at gasoline service stations (tons HC/gal.).

The values of Q_u, Q_e, Q_m, E_ℓ, E_u, and E_g are 7,560,808 gal./day, 568,500 gal./day, 2,098,124 gal./day, $2.225 \cdot 10^{-6}$ ton HC/gal., $1.05 \cdot 10^{-6}$ ton HC/gal., and $1.825 \cdot 10^{-6}$ ton HC/gal., respectively (see Chapter 18 for details on how these values are estimated). Substituting these values into Eq. 9.13 results in an estimate of the reduction in evaporative hydrocarbon emissions of $\overline{A} = 35.2$ tons HC/day.

9.3 SENSITIVITY ANALYSIS FOR ACTION 7

The cost estimates for the rescheduling, shut-down/start-up, delay of deliveries, canceled or delayed trips, and alternatives to taxi/livery services costs are only first approximations. Lack of data has forced a number of simplifying assumptions to approximate these costs. Based on these assumptions

these costs are between 42.1% and 39.1% of the total cost estimate for Action 7 for episodes of one to five days. Therefore, if all of these cost estimates are in error in the same direction by a factor of two, the total cost estimates would only change by at most a factor of 1.42. Since it is unlikely that all of these cost estimates will be in error in the same direction and the total cost estimate is not highly sensitive to errors in the more tenuous cost estimates, the total cost estimate should be fairly accurate.

The effects of the assumptions made on the rescheduling, shut-down/start-up, delay of deliveries, canceled or delayed trips, and alternatives to taxi/livery services costs and their effects on the total cost estimates are discussed below.

Sensitivity Analysis for Rescheduling Cost

The rescheduling cost estimate is sensitive to the assumed value of the average number of minutes required to reschedule each vehicle or worker affected by Action 7, i.e., α. It was assumed that α = 10 min. This is an assumed average figure, therefore, some rescheduling activities may take longer while others require less time.

Since the rescheduling cost estimate is proportional to α, an x% change in α would result in an x% change in the rescheduling cost estimate. However, the rescheduling cost is at most 5% of the total cost estimate, therefore, an x% change in α would result in an 0.05x% change in the total cost estimate. For example, if α is actually 20 min., then the rescheduling cost would at most be doubled (i.e., x = 100) but the total cost would only increase by 5% at most.

Sensitivity Analysis for Shut-Down/Start-Up Cost

The shut-down and start-up cost estimate for fleet trucks is sensitive to the assumed value of the proportionality factor between truck and airline shut-down and start-up costs, i.e., β. The airline cost is approximately \$250 per segment. It is assumed that β = 0.10, i.e., the average shut-down/start-up cost per interstate truck is \$25. The airline cost reflects, in part, a cost of \$800/hr to operate a commercial aircraft. (This cost includes the cost of crews, fuel, etc., but not depreciation; see Chapter 21 for

details). Heavy truck (i.e., trucks most likely used for interstate transport) operating costs, *including* depreciation, are about $0.55/mile [Ref. 17]. If a truck travels at an average speed of 55 mph, the hourly operating cost would be about $30.

If the shut-down/start-up cost per vehicle is proportional to the operating cost, then β would be less than 0.04. However, some trucks or cargos may have to be garaged or stored during an episode, resulting in possible storage expenses or idle time costs which are not incurred by airlines. For this reason, β is assumed to be greater than 0.04; it is set equal to 0.1.

Since the shut-down and start-up cost is proportional to β, it can be easily adjusted to reflect values of $\beta \neq 0.1$. A change in β of a factor of two would only change the total cost estimate of Action 7 by at most a factor of 1.069.

Sensitivity Analysis for Delay of Deliveries Cost

The cost of delays in deliveries is assumed to be reflected only in potential delays in retail good consumption. Furthermore, 50% of the non-food and drug retail sales is assumed to be delayed, i.e., $\lambda = 0.5$. However, if it is assumed that all goods and services will be delayed, then the maximum value of D would be $68,280 million/365 ≅ $187.1 million/day.* If $\lambda = 1$, then the maximum delay cost would be (187.1/21.33) = 8.77 times the values provided in Table 9.1. This would only result in a maximum increase in the total cost estimate of 10.2%. Therefore, the assumptions on the value of delayed goods and services do not greatly affect the total cost estimate.

A more subtle error that *could* be associated with the delayed delivery cost estimate is the method used to generate this cost. This method assumes that delay costs occur only if there are delays in consumption. However, production delays are possible which could require certain firms to close down operations. This situation, although possible, is probably unlikely to occur to any great extent. Most industries should keep sufficient inventories of input products to avoid shutdowns if deliveries are delayed for one reason

*See Appendix C for details on factor incomes.

or another. Therefore, only in unusual situations would delays in deliveries affect production. Thus, the approach used should be appropriate for estimating the cost of delays in deliveries.

Sensitivity Analysis for Canceled/Delayed Trip Cost

This cost is assumed to occur because some business or vacation trips depend on the use of rental cars. The resulting cost estimate is the most important cost component for which little or no information was gathered. It is also probably the least accurate cost calculation for Action 7. However, the estimated cost of canceled or delayed trips is less than 25% of the total cost estimate and a relatively large error will not significantly affect the total cost estimate.

Sensitivity Analysis for Alternatives-to-Taxi/Livery-Service Cost

This cost is dependent on the assumed value of the incremental time between the use of taxi/livery services and mass transit (or walking), i.e., δ. If δ is more broadly defined as the full differential value, including time, inconvenience, safety, etc., then the minimum value of δ would be 28.4 min. This would make the differential cost of taxi/livery and mass transit, i.e., d, equal to zero. This is a minimum value since the mass transit option would have been the first choice for lower values of δ.

By setting δ = 40 min., the value of d is \$0.963 or about \$1.00. Therefore, the alternative mode of travel cost, $\overline{C}$, is a normalized value; i.e. if δ is actually $\overline{\delta}$, then $\overline{C}$ would be $\overline{\delta}$ times the value used in the analysis. Since the delay cost component of the alternatives-to-taxi/livery-service cost is relatively small, this means that the alternative-to-taxi/livery-service cost would also be about $\overline{\delta}$ times those reported in Table 9.1. Furthermore, the cost of alternatives to taxi/livery services is at most 6.8% of the total cost. Therefore, a small change in δ would have a very small effect on the total cost estimate.

9.4 REFERENCES

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10 CLOSING OF LARGE PARKING FACILITIES -- ACTION 8

During a red alert parking lots and garages for more than 200 vehicles -- except those predominately serving residences; grocery stores; medical facilities; and rail, bus and air transportation terminals; those provided by employers primarily for employees; and comparable facilities designated by the IEPA -- must immediately curtail operations. The costs and emission reduction effects of this action are summarized in Table 10.1.

10.1 COSTS OF ACTION 8

The costs of this action include those of (1) notifying parking lot operators, employees and patrons; (2) delaying retail or entertainment expenditures; (3) delaying parking services; and (4) substituting mass transit for the automobile.

Notification Cost

The owner or operator of each parking facility required to submit an action plan is assumed to be informed by telephone that a red alert has been called. It is assumed that each phone call takes two minutes and that the calls are necessary only on the first day of the episode. Passengers not residing with the driver of canceled trips are assumed to be notified by

Table 10.1. Summary of the Costs and Emission Reduction Effects of Closing Large Parking Facilities

Episode Length (days)	Costs ($\$10^3$)					Emission Reductions (tons)	
	Notification	Delay of Purchases	Delay of Parking Expense	Mass Transit	Total	HC	NO_x
1	96.8	19.7	0.018	21.6	138	110	76.2
2	193	45.0	0.051	43.3	281	220	152
3	290	75.9	0.078	64.9	431	330	228
4	386	112	0.111	86.5	585	440	304
5	483	155	0.149	108	746	550	381

telephone of changes in plans. The employees and patrons are assumed to be notified through radio and TV announcements.

The costs of the telephone calls to the parking facility owners and operators are estimated as:

$$C = N \cdot (T + W/5040 + \overline{W}/5040) \qquad (10.1)$$

where:

$C \equiv$ the cost of notifying parking facility operators,

$N \equiv$ the number of operators to be contacted,

$T \equiv$ the cost of a telephone call,

$W \equiv$ the monthly wage rate of the person making the telephone call,

$\overline{W} \equiv$ the monthly wage rate of the person receiving the telephone call, and

The constant 5040 is the number of two-minute time periods in a working month (21 eight-hour days).

To estimate the operator notification costs, it is assumed that $T =$ \$0.10 and $W = \overline{W} =$ \$1,416, which is the median income of a low level management employee in metropolitan areas (i.e., Director of Personnel I).* The number of operators, N, to be notified is 417, which is the total of the 105 city garages and lots [Ref. 3],** 47 suburban garages and lots [Ref. 3], 165 shopping center lots [Ref. 4], and 100 miscellaneous garages and lots [Ref. 5] that are subject to the provisions of Action 8. Substituting these values of N, T, W, and $\overline{W}$ into Eq. 10.1 results in an estimated cost of notifying parking facility operators of \$276.

To estimate the cost of notifying passengers not residing with the driver, it is assumed that a two-minute telephone call is necessary for each passenger. The passenger notification cost for an n-day episode is:

$$\tilde{C} = \tilde{N} \cdot (T + 2 \cdot \tilde{W}/30) \cdot f \cdot \rho \cdot n \qquad (10.2)$$

where:

$\tilde{C} \equiv$ the passenger notification cost,

$\tilde{N} \equiv$ the total number of passengers involved per day,

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*From Table A.5.

**References are listed in Sec. 10.4.

$T \equiv$ the cost of a telephone call,

$\tilde{W} \equiv$ the value of an hour's time for the persons making and receiving the telephone call,

$f \equiv$ the fraction of persons that alters, delays, or cancels an automobile trip,

$\rho \equiv$ the fraction of passengers not residing with the driver, and

The constant 30 is the number of two-minute periods in an hour.

The number of passengers, $\tilde{N}$, is estimated from the data provided in Table 10.2; the table is based on information in Ref. 6. Summing the number of passengers results in an estimate of $\tilde{N}$ = 2.864 million persons per day. The cost of a telephone call, T, is assumed to be $0.10 and the value of time, $\tilde{W}$, is $2.50/hr [Ref. 7]. In Sec. 10.2 it is estimated that 1,508,463 trips are made daily to large parking facilities. This is 23.5% of the total number of trips made to destinations other than the home. If the number of passengers affected is proportional to the number of trips affected, then f = 0.235. It is assumed that $\rho = 0.5$, which is a mid-range estimate.

Substituting these values of $\tilde{N}$, T, f, $\tilde{W}$, and ρ into Eq. 10.2 yields:

$$C = 179{,}477 \cdot \rho \cdot n = 89{,}739 \cdot n \tag{10.3}$$

The radio and TV announcement costs, derived in Appendix D, are estimated to be $6,800/day. Therefore, the notification costs for an n-day episode are estimated to be:

$$C' = (89{,}739 + 6{,}800) \cdot n + 276 \tag{10.4}$$

Notification costs for episodes of various lengths are provided in Table 10.1.

Table 10.2. Number of Automobile Trips and Passengers

Trip Purpose	Thousands of Trips	Thousands of Passengers
Work	1,731	327
Work-Related	512	29
School	108	225
Shopping	1,482	749
Social/Recreational	1,314	1,125
Personal Business	754	354
Other	510	55

Delay of Purchases

Because of the types of parking facilities exempted from Action 8 (listed above), it is assumed that the intent of the action is to limit the use of the automobile for shopping and entertainment (social) purposes. It is assumed that these activities are delayed until the episode is over and that they occur within a week after the episode ends. To estimate this delay cost for an n-day episode the following equation is used:

$$\hat{C} = \sum_{t=1}^{n} D \cdot P_t = D \cdot \sum_{t=1}^{n} P_t \tag{10.5}$$

where:

$\hat{C} \equiv$ the cost of delaying retail and entertainment expenditures,

$D \equiv$ the average daily expenditure postponed, and

$P_t \equiv$ the delay factor for assumed minimum and maximum delays.

In 1972, retail stores in the Chicago SMSA sold over $17 billion of goods. In addition, another $561 million was spent on amusement and recreational activities. However, parking lots primarily servicing food and drug stores are exempt from the regulation. Other retail outlets do not depend on large parking facilities to service their customers; included in this group are mobile home dealers, automobile dealers, gasoline service stations, and drinking places. The 1972 sales in these businesses are provided in Table 10.3.

Subtracting the value of sales from retail establishments that are most likely unaffected by the regulation from total retail sales, and adding the value of expenditures for amusement and recreation, provides an estimate of 1972 sales in businesses that *could* be affected by Action 8 of $9.461 billion. Adjusting for the population changes between 1972 and 1974 and converting to 1974 dollars, this figure becomes $11.242 billion.*

Not all of these sales or services occur in establishments that would be affected by Action 8. If δ is the fraction of these sales that would be affected, then:

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* 1974$ = 1972$ • (1974 Chicago SMSA population/1972 Chicago SMSA population) • (1974 Consumer Price Index/1972 Consumer Price Index). See Tables A.1 and A.6 for population and price index data.

Table 10.3. Selected Retail and Service Sales in the Chicago SMSA in 1972

Type of Business, SIC Code	1972 Sales ($\$10^9$)
Total Retail,[a] 50	17.231
Retail Establishments Not Likely to Be Affected by Action 8[a]	
Mobile Home Dealers, 527	0.028
Food Stores, 54	3.318
Automobile Dealers, 55 (excluding 554)	2.973
Gasoline Service Stations, 554	1.028
Drinking Places, 5813	0.275
Drug Stores, 591	0.709
Amusement and Recreation,[b] 78, 79	0.561

[a]Ref. 1.

[b]Ref. 2.

$$D = (11.242 \times 10^9/365) \cdot \delta \tag{10.6}$$

Setting δ equal to 0.7 provides an estimate of D = \$21,559,881. Substituting this value of D into Eq. 10.5, along with the values of P_t provided in Table 10.4, results in the estimated cost of delayed purchases provided in Table 10.1.

Delayed Parking Expenses

Parking expenses will also be delayed if a trip is postponed. To estimate this delay cost, Eq. 10.5 is used with the variable D redefined as the delayed expenditures for parking.

The value of D is estimated as:

$$D = \left(\sum_{i=1}^{4} N_i \cdot P_i \cdot G_i \cdot U_i \right) \alpha \tag{10.7}$$

where:

$N_i \equiv$ the number of parking facilities of type i;

Table 10.4. Assumed Minimum and Maximum Delays and Corresponding Delay Cost Factors

t	Minimum Delay (days)	Maximum Delay (days)	Delay Factor[a] P_t
1	1	8	0.000913
2	2	9	0.001174
3	3	10	0.001435
4	4	11	0.001695
5	5	12	0.001956

[a]A 10% discount rate is assumed; see Table A.7 and discussion in Sec. 2.1.

P_i ≡ the average number of parking spaces in facility type i;

G_i ≡ the average charge per customer;

U_i ≡ the daily utilization rate (vehicles/parking space);

i ≡ parking facility type: 1 = City of Chicago garages, 2 = City of Chicago lots, 3 = suburban Cook County facilities, and 4 = other suburban facilities; and

α ≡ the fraction of the parking revenues that is delayed.

Based on a survey conducted as part of the study, the values of N_i for i = 1, 2, 3, and 4 are 68, 37, 30, and 17, respectively. A sample of seven central business district (CBD) City-of-Chicago-owned garages was taken. In Garages #1, 2, 3, 4, 5, 8, and 9 of the Chicago Parking Bureau, 5,095 parking spaces are available -- an average of 728. These garages served 156,893 regular customers during May of 1976. In addition, 1,576 patrons had monthly or special passes. By dividing the number of regular customers by 30 days and adding the monthly and special parkers, it is estimated that 6,806 patrons are served daily. Dividing the daily number of customers by the parking spaces available, a daily utilization rate of 1.34 is determined. This utilization rate is assumed to be constant for all parking facilities, i.e., U_i = 1.34 for all i. Furthermore, P_1 = 728.

A suburban survey showed that the average number of parking spaces available per facility is 310. A lower estimate of 230 is used for Chicago

parking lots where land costs are higher and mass transit is more accessible. Thus, $P_2 = 230$ and $P_3 = P_4 = 310$.

There is a wide variation in the prices charged parkers, with the highest prices at the Chicago parking garages. At city-owned garages in Chicago, \$0.75 is charged for the first hour with \$0.25 for each additional hour plus a \$0.15 parking tax. At commercially owned garages in the CBD, rates vary between \$3.00 and \$4.25 for eight hours of parking and evening charges vary from \$1.00 to \$2.00. Non-CBD city-owned parking lots charge, on the average, \$0.20 for the first hour and \$0.10 for all following hours, plus the \$0.15 parking tax. The survey of suburban cities and villages indicated that an average of \$0.89 was charged per customer for parking in suburban lots. Using this information, the following average 1974 parking costs per customer are assumed: $G_1 = \$2.50$ for Chicago garages, $G_2 = \$1.00$ for Chicago lots, and $G_3 = G_4 = \$0.75$ for suburban parking facilities.

Substituting these values of N_i, P_i, G_i, and U_i into Eq. 10.7 yields:

$$D = 191{,}885 \cdot \alpha \tag{10.8}$$

Setting $\alpha = 0.1$ and substituting the resulting value of D into Eq. 10.5, along with the values of P_t provided in Table 10.4, the parking delay cost estimates in Table 10.1 are calculated. It is important to note that if α is set equal to 1 the maximum delay cost would by only ten times that reported in Table 10.1.

Mass Transit Substitute

Rather than being postponed because parking facilities are closed, some trips may be canceled or they may be made using public transit. The most likely trips to be canceled are shopping, recreation/social, or work-related trips. If the value of these trips was great enough they would be made using public transit or if public transit was not available they would most likely be made on another day. Therefore, it can be assumed that the value of canceled trips is relatively small and that it can be ignored without significantly affecting the cost estimate.

The cost of using mass transit rather than the automobile is equal to the difference in costs between the two modes of travel. Because the automobile would have been used if an episode had not occurred, it can be assumed

that the cost of using a car is less than the cost of using mass transit for the individuals affected. The cost of using each mode of transit must include the value of time; a value of time of $2.50 per hour is assumed [Ref. 7].

The cost of using transit is estimated to be:

$$T = \overline{N} \cdot (2 \cdot F + \beta \cdot \overline{F}) \tag{10.9}$$

where:

$T \equiv$ the total cost of using transit,

$\overline{N} \equiv$ the number of additional transit riders,

$F \equiv$ the one-way transit fare,

$\overline{F} \equiv$ the value of time, and

$\beta \equiv$ the increased travel time.

The number of additional transit riders is estimated to be:

$$\overline{N} = \left(\sum_{i=1}^{4} N_i \cdot P_i \cdot U_i \cdot Q_i \right) \left(1 - \alpha \right) \tag{10.10}$$

where:

i, N_i, P_i, U_i, and α are defined as in Eq. 10.7, and

$Q_i \equiv$ the average occupancy of vehicles driven to each type of parking facility; values of Q_i are given in Table 10.5.

Table 10.5. Auto Occupancy by Trip Purpose and Location of Trip Destination

	Occupancy (persons/auto)		
Trip Purpose	Loop Destination (Q_1, Q_2)	Chicago Non-Loop Destination (Q_3)	Suburban Destination (Q_4)
Shopping	2.09	1.58	1.49
Social/Recreational	2.23	1.89	1.77
Work Trips	1.28	1.19	1.19
Related Business	1.06	1.08	1.05
WEIGHTED AVERAGE	1.38	1.45	1.45

Source: *1970 Travel Characteristics*, Chicago Area Transportation Study and the Northwestern Indiana Regional Planning Commission (Nov. 1975).

The value of α is assumed to be the same as it was in Eq. 10.7, i.e., 0.1. If it is assumed that no trips are canceled (we have effectively done so) and if equal proportions of trips to each type of parking facility are delayed, then $(1 - \alpha)$ is the fraction of persons that uses paid parking facilities, is affected by Action 8, and will use public transit. Since α is assumed to equal 0.1, it is assumed that 90% of the people who use large paid parking lots will substitute mass transit for the automobile during an episode. This is not an unreasonable assumption since many of the trips affected will be work trips and mass transit is available in most areas where large parking facilities charge for parking.

Using these data, the estimated number of additional transit riders is $\overline{N} = 135{,}589 \cdot (1 - \alpha) = 122{,}030$. Setting $F = \$0.44$ (this is the CTA fare of \$0.50 adjusted to 1974 dollars) and $\overline{F} = \$2.50$, the transit cost equation (Eq. 10.9) becomes:

$$T = 305{,}075 \cdot \beta + 107{,}386 \qquad (10.11)$$

It is likely that the automobile will be used to drive to the transit station. Parking costs may also be incurred at the station.* The cost of using a car is assumed to be \$0.13 per mile, which is the \$0.15 allowance given by the IRS for tax purposes adjusted to 1974 dollars. The total number of vehicles affected is 87,536, which is estimated using Eq. 10.10 and setting $Q_i = 1.0$. Assuming an average parking cost of \$0.50 per vehicle and an average round trip of five miles to the transit station results in a driving/parking cost of $87{,}536 \cdot (0.13 \cdot 5 + 0.50) = \$100{,}667$. This cost** must be added to the transit cost estimated above to obtain the total cost of making a trip using transit, $\overline{T}$:

$$\begin{aligned} \overline{T} &= 305{,}075 \cdot \beta + 107{,}386 + 100{,}667 \\ &= 305{,}075 \cdot \beta + 208{,}053 \qquad (10.12) \end{aligned}$$

The cost saving of not using an automobile is estimated to be:

$$\overline{A} = \overline{N} \cdot 0.13 \cdot L + 191{,}885 \cdot (1 - \alpha) \qquad (10.13)$$

---

*Parking lots at transit stations are not closed by Action 8.

**The cost of getting from a transit station to the final destination is assumed to be equal to the cost of getting to the final destination from the parking garage normally used.

where:

$\overline{A}$ ≡ the automobile cost savings,

L ≡ the average trip length,

α and $\overline{N}$ are defined as in Eqs. 10.7 and 10.9, respectively,

The constant 0.13 is the cost per mile of running an automobile, and

The constant 191,885 is the total daily cost of parking in the affected parking facilities.

The average one-way airline distances for work, related business, shopping, and social/recreational trips in the Chicago area are 7.0, 7.4, 3.0, and 5.7 miles, respectively [Ref. 6]. The weighted average length of these trips is 5.5 airline miles. Airline miles are converted to actual miles traveled by multiplying by 1.25 [Ref. 3]. Therefore, each round trip is estimated to be $L = 2(5.5)(1.25) = 13.75$ miles. With $\alpha = 0.1$, $\overline{N}$ equals 122,030 and the automobile cost savings, $\overline{A}$, are $390,824.

The estimated cost of substituting mass transit for the automobile is:

$$\overline{C} = \overline{T} - \overline{A} = 305{,}075 \cdot \beta - 182{,}771 \tag{10.14}$$

Since we expect $\overline{C}$ to be greater than zero for the individuals affected by the regulation, β must be at least equal to 0.6.* If the average waiting time for a transit vehicle is 10 min., an average of 10 min. is spent to and from the transit station, and the time of travel is the same for both modes, then the increase in travel time will be 40 min. This implies $\beta = 0.67$. Other scenarios of waiting and travel time for the two modes of travel can be hypothesized to make $\beta = 0.67$. A greater value of β is unlikely for trips that average 13.75 miles. The point here is that this value of β seems reasonable. The mass transit costs given in Table 10.1 are calculated using a value of $\beta = 0.67$.

10.2 EMISSION REDUCTION EFFECTS OF ACTION 8

The vehicular source emission reduction effects of Action 8 are estimated from the following equation:

$$R_p = A_p + B_p \tag{10.15}$$

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* For simplicity β is defined as equal to the time difference between a mass transit trip and an automobile trip. In reality it reflects a number of variables such as personal preference, inconvenience, safety, etc.

where:

R_p ≡ emission reduction of pollutant p (tons/day);

p ≡ pollutant: 1 = hydrocarbons, and 2 = nitrogen oxides;

A_p ≡ emission reduction of pollutant p due to the curtailment of passenger auto traffic (tons/day); and

B_p ≡ emission reduction of pollutant p due to the increase in average traffic speeds during the peak periods resulting from the traffic curtailment (tons/day).

The variable A_p is calculated as follows:

$$A_p = \sum_{i=1}^{4} V_j \cdot E_p(S_j)/907{,}184 \tag{10.16}$$

where:

j ≡ traffic segment: 1 = expressway peak, 2 = expressway off-peak, 3 = arterial peak, and 4 = arterial off-peak;

V_j ≡ vehicle miles of passenger autos curtailed in traffic segment j (miles/day);

$E_p(S_j)$ ≡ emission rate of pollutant p of passenger autos at average speed S_j (grams/mile); and

The constant 1/907,184 converts grams to tons.

The variable B_p is calculated as:

$$B_p = \sum_{j=1,3} \sum_{i=1}^{9} V^*_{ij} \cdot [\overline{E}_{pi}(S_j) - \overline{E}_{pi}(S'_j)]/907{,}184 \tag{10.17}$$

where:

i ≡ vehicle class (see Appendix E);

V^*_{ij} ≡ Vmt of class i vehicles during traffic segment j, after the action (miles/day). The Vmt of all vehicle classes after the action will be the same as before the action except for passenger autos. Passenger auto travel is reduced V_j miles per day in traffic segment j;

$\overline{E}_{pi}(S_j)$ ≡ emission rate of pollutant p for vehicle class i at average speed S_j before the action (grams/mile); and

$\overline{E}_{pi}(S'_j)$ ≡ emission rate of pollutant p for vehicle class i at average speed S'_j after the action (grams/mile).

The following assumptions are implicit in Eqs. 10.15 - 10.17: (1) only passenger auto traffic is affected by the action; and (2) this traffic is completely curtailed, substitute trips will not be made to facilities with small

lots, people will not have friends drive them to the facilities and drive around until their business is complete, etc.; these reactions may actually result in increased Vmt and emissions.

Table 10.6, which contains data on the number of parking lots in the SMSA with more than 200 spaces of the type covered by the regulation, shows that there are 778,184 parking spaces in such SMSA lots: 72,584 in city and suburban facilities, and 705,600 in other parking facilities.

In Sec. 10.1 it was estimated that parking spaces in city and suburban facilities had an average utilization rate of 1.34. The parking space turnover rate for all shopping centers is 2.87 cars/space/day [Ref. 3]. This figure includes small convenience centers so the number for larger lots is probably smaller. It is assumed that the average utilization rate is 2.0 for the 705,600 shopping center and entertainment parking spaces of lots with more than 200 spaces. Therefore, the estimated number of daily trips made to large parking lots is:

$$\begin{aligned} 1{,}508{,}463 &= 72{,}584 \cdot 1.34 + 705{,}600 \cdot 2.0 \\ &= 97{,}262 + 1{,}411{,}200 \end{aligned}$$

Table 10.6. Parking Facility Data for Garages and Lots with More than 200 Spaces

Lot Type	No. of Lots	Average Spaces/Lot	Total No. of Spaces
City of Chicago Garages	68[a]	728[d]	49,504
City of Chicago Parking Lots	37[a]	230[c]	8,510
Suburban Lots and Garages	47[a]	310[d]	14,570
Shopping Centers	165[b]	2,640[b]	435,600
Entertainment	100[c]	2,700[c]	270,000
TOTAL	417	---	778,184

[a]Data from Chicago Area Transportation Study.

[b]Based on data from Ref. 4.

[c]Estimate.

[d]Based on sample data discussed in text.

The number of daily trips to city and suburban large parking facilities is 97,262 and to other large parking facilities 1,411,200.

The average round trip for persons using the city and suburban parking facilities was previously estimated to be 13.75 miles. The average *one-way* trip lengths for shopping, social/recreational, and personal business are 3.75, 7.13, and 5.63 miles respectively. [Chicago Area Transportation Study (CATS) data indicate that average trip lengths, in airline miles, for purposes of shopping, social/recreational, and personal business are 3.0, 5.7, and 4.5 miles, respectively [Ref. 6]. Multiplying by the airline correction factor of 1.25, as prescribed by CATS, the estimated trip mileages are 3.75, 7.13, and 5.63 miles, respectively]. Trips with these purposes are the most likely to be affected by closing of shopping centers and entertainment parking lots. A weighted average *round-trip* length for these purposes is assumed to be 10.8 miles.

Some individuals who make trips to city and suburban parking facilities are assumed to use public transit during an episode. This involves an automobile trip to the transit station with an assumed average round-trip length of 5.0 miles. If $(1 - \alpha)$ is the fraction of persons that substitutes mass transit for the automobile, then the resulting Vmt reduction is:

$$\overline{V} = [97{,}262 \cdot 13.75] - [97{,}262 \cdot 5.0 \cdot (1 - \alpha)] \tag{10.18}$$

Setting $\alpha = 0.1$, as was done to estimate mass transit costs, results in an estimate of $\overline{V} = 899{,}674$ miles/day.

Assuming that trips to city and suburban areas include work and work-related trips, then some of these will be made during peak periods. If the arterial, expressway, peak, and non-peak Vmt distribution is the same for these trips as it is for traffic in general, then:

$$\overline{V}_j = 899{,}674 \cdot k_j \tag{10.19}$$

where:

$\overline{V}_j \equiv$ the passenger auto Vmt to large city and suburban parking facilities in traffic segment j (miles/day), and

$k_j \equiv$ the fraction of passenger auto Vmt occurring in traffic segment j.

From Table E.14 the values of k_j are 0.081, 0.179, 0.230, and 0.510 for j = 1, 2, 3, 4, respectively. Thus, $\overline{V}_j$ equals 72,874, 161,042, 206,925, and 458,834, respectively.

The Vmt curtailed by persons taking shopping, social/recreational, and personal business trips are 1,411,200 • 10.8 = 15,240,960. As described in Appendix E, it is assumed that shopping, social/recreational, and personal business trips primarily occur during non-peak periods. If the Vmt arterial-expressway distribution for trips to shopping center and recreational parking facilities is the same as for traffic in general, then:

$\hat{V}_2$ = 15,240,960 • 0.259 = 3,947,409 miles, and

$\hat{V}_4$ = 15,240,960 • 0.741 = 11,293,551 miles,

where $\hat{V}_j$ is the Vmt in traffic segment j from trips to large shopping center and entertainment parking facilities.

The estimated value of V_j in Eq. 10.16 is:

$$V_j = \overline{V}_j + \hat{V}_j \tag{10.20}$$

For j = 1 to 4, the values of V_j are 72,874, 4,108,451, 206,925, and 11,752,385 miles/day, respectively.

Using these values of V_j in Eq. 10.16, along with the emission factors $E_p(S_j)$* for automobiles driven in each of the respective traffic segments, results in estimated emission reductions from curtailing traffic of:

A_1 = 99.6 tons HC/day, and

A_2 = 75.8 tons NO_x/day.

The emission reductions, B_p, due to the increased traffic speed are based on the Vmt data in Table 10.7. It is estimated that the average speed

Table 10.7. Speed Increase Data

Traffic Segment	Vmt before Action (miles/day)	Vmt after Action (miles/day)	Vmt per Hour after Action	Avg. Speed after Action[a] (mph)
Expressway Peak	7,451,000	7,382,066	1,476,413	43.8
Arterial Peak	21,393,000	21,186,075	4,237,215	12.2

[a]Based on peak speed adjustment equations (Appendix F).

*$E_1(S_j)$, for j = 1 to 4, = 4.47, 4.36, 8.93, and 5.98 grams HC/mile; and $E_2(S_j)$, for j = 1 to 4, = 4.66, 4.84, 3.96, and 4.06 grams NO_x/mile. See Tables E.4 and E.5.

of arterial peak traffic will increase from 11.9 mph to 12.2 mph and that expressway peak traffic will experience a speed increase from 43.7 mph to 43.8 mph. Emission factors, $\overline{E}_{pi}(S_j')$, for all vehicle classes are calculated at these new average speeds (not reproduced here because of the large quantity of data). The V^*_{ij}'s in Eq. 10.17 are the Vmt estimates before the action was in effect,* except for passenger autos. Since passenger auto travel is reduced, the V^*_{ij}'s (here the subscript i refers to the passenger auto or low annual mileage auto vehicle classes) are equal to the passenger auto Vmt estimates before the action* minus the Vmt reductions (V_j's) in the respective traffic segments. Using these data in Eq. 10.17 gives:

B_1 = 2.75 tons HC/day, and

B_2 = 0.380 tons NO_x/day.

The vehicular source effectiveness of Action 8 is then, from Eq. 10.15:

R_1 = 99.6 + 2.75 = 102 tons HC/day, and

R_2 = 75.8 + 0.380 = 76.2 tons NO_x/day.

The total HC emission reduction is the sum of R_1 and the evaporative emission reduction due to reduced average sales of gasoline. The evaporative emission reduction is estimated in Appendix G to be 7.52 tons HC/day. Therefore, the total HC emission reduction is:

102 + 7.52 = 110 tons HC/day.

10.3 SENSITIVITY ANALYSIS FOR ACTION 8

The notification cost is 70.1% of the total estimated cost of Action 8 for a one-day episode and 64.7% for a five-day episode. Furthermore, the notification cost is sensitive to the fraction of passengers not residing with the driver, ρ. Therefore, the total cost estimate of Action 8 is highly sensitive to the assumed value of ρ.

The value of ρ ranges between 0 and 1, making the notification cost of a one-day episode range between $7,076 and $186,553 and the total cost estimate range between $48,400 and $228,000. The cost/effectiveness ratio of the sum of HC and NO_x emission reductions ranges between $272/ton and $1,280/ton.

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*See Table E.16.

Setting $\rho = 0.5$ results in a mid-range estimate for the notification cost. For a one-day episode, the notification cost is estimated to be \$96,800 and the total cost \$138,000. The cost/effectiveness ratio of the sum of HC and NO_x emission reductions is \$774/ton.

The delay-of-purchases cost is sensitive to the assumed fraction of selected sales that is affected by Action 8, δ. The delay-of-purchases cost is 14.3% of the total cost of a one-day episode and 20.8% of a five-day episode's cost. Therefore, the total cost estimate is relatively sensitive to the assumed value of δ.

Because of the dominance of retail sales in regional shopping centers and downtown Chicago, δ will be relatively large, i.e., greater than 0.5; δ is thus set equal to 0.7. Therefore, within a reasonable range of δ the delay-of-purchases cost will vary by less than ±43% and the total cost by less than ±9%. Since the emission reduction estimates are not affected by the assumed value of δ, the cost/effectiveness ratios will also only be affected by at most ±9%.

Equation 10.14 can be rewritten as:

$$\overline{C} = 338{,}972 \cdot (1 - \alpha) \cdot \beta - 203{,}078 \cdot (1 - \alpha)$$

Therefore, the estimated mass transit cost is a function of two variables for which little information is available, i.e., α and β. However, it is known that α ranges between 1 and 0 and that a reasonable range for β is between 1 and 0.6. As α approaches 1, the mass transit costs become small independently of β. For example, if $\alpha = 0.9$ and $\beta = 0.67$, then $\overline{C}$ = \$2,403 per day. Similarly, as β approaches 0.6 the mass transit costs become small independently of α. For example, if $\beta = 0.61$ and $\alpha = 0.1$, then $\overline{C}$ = \$3,325 per day.

On the other hand, if α is small and β is large, then the mass transit costs can increase significantly. For example, if $\alpha = 0.1$ and $\beta = 1$, then $\overline{C}$ = \$122,000 per day.

The emission reduction effects are dependent on the value of α (see Eq. 10.18) but are independent of the value of β. However, as α ranges from 0 to 1 the HC reductions range between 110 and 115 tons and the NO_x reductions range between 76.0 and 78.4 tons. The emission reduction effects are insensitive to the value of α because the number of trips to shopping centers and

entertainment parking facilities is about 15 times greater than the number of trips to city and suburban parking facilities. Since α only affects the Vmt and, therefore, the emission reduction effect for trips to city and suburban parking facilities, the value of α has only a slight effect on emission reductions.

Because the emission reductions are not significantly affected by α and β and costs are, the cost/effectiveness ratios of the action are significantly affected. For example with $\alpha = 0.9$ and $\beta = 0.67$, the cost/effectiveness ratio for HC is $119/114 = \$1.04 \cdot 10^3$/ton. For $\alpha = 0.1$ and $\beta = 1$ the cost/effectiveness ratio for HC is $239/110 = \$2.17 \cdot 10^3$/ton.

The estimates given in Table 10.1 are mid-range estimates. These are considered to be good estimates because of the reasons given for setting $\alpha = 0.1$ and $\beta = 0.67$. With these values of α and β the cost/effectiveness ratio for HC is $138/110 = \$1.25 \cdot 10^3$/ton.

10.4 REFERENCES

1. *Census of Retail Trade, Illinois, 1972,* Table 2: Standard Metropolitan Statistical Areas, U.S. Bureau of the Census (1976).

2. *Census of Selected Service Industries, Illinois, 1972,* Table 2: Standard Metropolitan Statistical Areas, U.S. Bureau of Census (1976).

3. Chicago Area Transportation Study, telephone conversations or meetings with staff (1976).

4. *Directory of Shopping Centers in the United States and Canada,* Vol. XIV, 14th Ed., The National Research Bureau, Inc. (1973).

5. Obtained from informal survey by project staff. Includes sport arenas, theaters, restaurants, etc.

6. *Purpose, Mode, Time of Day: 1970 Travel Characteristics,* Chicago Area Transportation Study and the Northwestern Indiana Regional Planning Commission, CATS 372-491 (November 1975).

7. Zerbe, R.O., and K.G. Croke, *Urban Transportation for the Environment,* Ballinger Publishing Co., Cambridge, Mass. (1975).

11 CURTAILMENT OF ROADWAY REPAIRS -- ACTION 9

During a red alert, road repairs and maintenance not necessary for immediate safety and which, if suspended, will expedite the flow of vehicle traffic, are prohibited. The costs and emission reduction effects of this action are presented in Table 11.1.

11.1 COSTS OF ACTION 9

The primary costs of curtailing roadway repairs are the costs of (1) notifying the appropriate governmental agencies' employees and their subcontractors, (2) the delay in making the repairs, and (3) the rescheduling of the repair work. Because large roadway construction projects will most likely not be curtailed, it is assumed that the work can be made up without the use of overtime labor. The assumptions, procedures, and data used to estimate these costs are discussed below.

Notification Cost

Each government agency responsible for roadway repairs is assumed to be informed by telephone that a red alert has been called in order to ensure proper enforcement of the action. Furthermore, this is assumed to be necessary only on the first day of the episode. Because the employees and subcontractors are assumed to have been briefed on the actions they should take during a red alert, radio and TV announcements are assumed sufficient to notify them of the episode.

Table 11.1. Summary of the Costs and Emmission Reduction Effects of Curtailing Road Repairs

Episode Length (days)	Costs ($\$10^3$)				Emission Reductions (tons)	
	Notification	Delay of Repair	Rescheduling	Total	HC	NO_x
1	6.96	0.09	1.02	8.07	2.00	-0.10
2	13.8	0.209	2.04	16.0	4.00	-0.20
3	20.6	0.352	3.06	24.0	6.00	-0.30
4	27.4	0.521	4.08	32.0	8.00	-0.40
5	34.2	0.717	5.10	40.0	10.0	-0.50

Assuming each telephone call lasts two minutes, the costs of the telephone calls are estimated as:

$$C = N \cdot (T + W/5040 + \overline{W}/5040) \tag{11.1}$$

where:

$C \equiv$ the cost of notifying government agencies,

$N \equiv$ the number of agencies to be contacted,

$T \equiv$ the cost of a telephone call,

$W \equiv$ the monthly wage rate of the person making the telephone call,

$\overline{W} \equiv$ the monthly wage rate of the person receiving the telephone call, and

The constant 5040 is the number of two-minute time periods in a working month.

To estimate the agency notification costs, it is assumed that $T = \$0.10$ and $W = \overline{W} = \$1416$, which is the median income of a low level management employee in metropolitan areas (i.e., Director of Personnel I).* The number of agencies to be notified is 242: there are 235 municipal, six county, and one state governments in the Chicago area. Substituting the values of N, T, W, $\overline{W}$ into Eq. 11.1 results in an estimated cost of notifying government agencies of \$160.

The radio and TV announcement costs, derived in Appendix D, are estimated to be \$6,800/day. Therefore, the notificiation cost for an n-day episode is estimated to be:

$$\overline{C} = 6800 \cdot n + 160 \tag{11.2}$$

The notification costs for various length episodes are provided in Table 11.1.

Delay Cost

The value of roadway repairs is assumed to equal the expenditure made for them. Therefore, the delay cost for an n-day episode is:

$$\hat{C} = \sum_{t=1}^{n} D \cdot P_t = D \cdot \sum_{t=1}^{n} P_t$$

where:

*From Table A.5.

$\hat{C}$ ≡ the delay cost of curtailing road repairs,

D ≡ the average daily expenditure made for roadway repairs, and

P_t ≡ the delay factor for assumed minimum and maximum delays.

An example will help to clarify the interpretation of Eq. 11.3. Consider a three-day episode. The repairs delayed during the first day are assumed to be postponed a minimum of three days (because the episode is three days long) and a maximum of 10 days (because it is assumed that the repairs will be made up within one week after the episode is over). The repairs delayed during the second day of the episode have only a two-day minimum delay, and it is assumed that these services are also made up within a week after the episode ends. Similarly, the services delayed on the last day of the episode will have a minimum delay of only one day and a maximum delay of eight days.

Table 11.2 summarizes the minimum/maximum delay assumptions used and the resulting delay factors, P_t. The procedure used to estimate the delay factors is described in Chapter 2; delay factors for other minimum/maximum delay assumptions are provided in Table A.7.

The total annual expenditure for highways by local governments in 1971 in the Chicago SMSA was $206,224,000 [Ref. 1],* which is equivalent to a per capita expenditure of $29.55. An estimated 7,141,510 persons

Table 11.2. Assumed Minimum and Maximum Delays and Corresponding Delay Factors

t	Minimum Delay (days)	Maximum Delay (days)	Delay Factor[a] P_t
1	1	8	0.000913
2	2	9	0.001174
3	3	10	0.001435
4	4	11	0.001695
5	5	12	0.001956

[a] A 10% discount rate is assumed; see Table A.7 and discussion in Sec. 2.1.

*References are listed in Sec. 11.4.

lived in the Chicago SMSA in 1974.* The consumer price index between 1971 and 1974 changed from 121.3 to 147.7; therefore, the estimated annual expenditure made for highways by local governments in 1974 was: 7,141,510 • $29.55 • (147.7/121.3) = $256,961,009.

The Illinois Department of Transportation had a proposed budget for roadway improvements of $109,640,000 in fiscal year 1974 [Ref. 2]. This includes both state and federal expenditures on highway improvements in the Chicago area, including Kendall and Kankakee Counties. About 98.23% of the population of the eight-county area lives in the six-county study area. Therefore, it is estimated that $109,640,000 • 0.9823 = $107,700,222 was spent on highways in the six-county area by federal and state government in 1974.** Combining the federal, state, and local expenditures yields total expenditures on highways of: $256,961,009 + $107,700,222 = $364,661,231.

If α is the percentage of the total highway expenditures that is delayed because of an episode, then the average daily expenditure delayed is:

$$D = 364{,}661{,}231 \cdot \alpha / 365 \tag{11.4}$$

Setting $\alpha = 0.1$ results in an estimate of D = $99,907. Substituting this value of D and the values of P_t provided in Table 11.2 into Eq. 11.3 yields the estimated daily costs for Action 9 shown in Table 11.1.

Rescheduling Cost

To estimate the rescheduling cost it is assumed that an average of one-half hour per day is required by each government agency to reschedule repair operations. This may be an overestimate for agencies with only a few repair activities. However, for larger agencies which are responsible for making many repairs, more time may be required to reschedule operations. A half-hour seems to be a reasonable average rescheduling time.

For an n-day episode the rescheduling costs are estimated as:

$$\tilde{C} = N \cdot (\hat{W}/336) \cdot n \tag{11.5}$$

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*See Appendix A.

**It is not clear if any of these dollars were distributed to local governments. If this is the case then the total estimate of expenditures on highways in the six-county Chicago area will be high. However, the error introduced is small.

where:

$\tilde{C} \equiv$ the rescheduling cost,

$N \equiv$ the number of government agencies,

$\tilde{W} \equiv$ the monthly wage rate of the person doing the rescheduling, and

The constant 336 is the number of half-hour periods in a working month of 21 eight-hour days.

Assuming that lower management personnel are responsible for scheduling repair work, then W = \$1,416 (see Table A.5.). With N = 242, Eq. 11.5 becomes:

$$\tilde{C} = 242 \cdot (1416/336) \cdot n = 1020 \cdot n.$$

The rescheduling costs provided in Table 11.1 are calculated using Eq. 11.6.

11.2 EMISSION REDUCTION EFFECTS OF ACTION 9

The following activities have been mentioned as delayable road repairs by the Illinois EPA:*

- Centerline painting,
- Grass cutting,
- Landscaping,
- Street cleaning,
- Minor repairs to surfaces, and
- In some cases extensive work when the cancellation will allow extra lanes to be opened.

From this list and the wording of the action it appears that the primary objective is to eliminate traffic congestion and thereby increase average vehicle speeds, which could result in an emission reduction. Although HC reductions would occur from the curtailment of painting lines and laying asphalt, and NO_x and HC reductions would occur from stopping road repair and maintenance vehicles, it is assumed that these emissions reductions are very small, and therefore they are not considered in this analysis.

The emission change due to the action is calculated from the following equation:

$$R_p = \sum_{j=1}^{4} \sum_{i=1}^{9} V_{ij} \cdot \phi \cdot [E_{ip}(S_j) - E_{ip}(S_j + \sigma)]/907,184 \qquad (11.7)$$

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*See testimony by Jack G. Colbenz, Pulic Hearing No. R75-4, June 3, 1975.

where:

R_p ≡ emission reduction of pollutant p due to the action (tons/day);

p ≡ pollutant: 1 = hydrocarbons, and 2 = nitrogen oxides;

j ≡ traffic segment: 1 = expressway peak, 2 = expressway off-peak, 3 = arterial peak, and 4 = arterial off-peak;

i ≡ vehicle class (see Appendix E);

V_{ij} ≡ Vmt of class i vehicles during period j (miles/day);

ϕ ≡ fraction of Vmt (of vehicles in all vehicle classes) which experiences a speed increase due to curtailing road repair and maintenance;

$E_{ip}(S_j)$ ≡ emission factor for vehicles of class i and pollutant p at average speed S_j before curtailing road repairs (grams/mile);

$E_{ip}(S_j + \sigma)$ ≡ emission factor for vehicles of class i and pollutant p at speed $(S_j + \sigma)$ after curtailing road repairs. The increase in speed for all traffic segments is equal to σ mph (grams/mile); and

The constant 1/907,184 converts grams to tons.

The above formulation assumes that the same fraction of each V_{ij} experiences the same increase in speed. For example, if $\phi = 0.05$, then the emission reduction is calculated for the case where five percent of the auto, truck, and bus Vmt in each traffic segment experiences a speed increase of σ mph.

The Vmt estimates (V_{ij}) and emission factors [$E_{ip}(S_j)$] before curtailing road repairs are given in Table E.16, and Tables E.4, and E.5, respectively. Data on the fraction of the Vmt presently affected by road repair and maintenance, and the speed increase from curtailing these activities (ϕ and σ in Eq. 11.7) could not be obtained. Figures 11.1 and 11.2 illustrate the estimated emission changes for different values of these variables.

From Fig. 11.1 it is apparent that the greater the speed change and the greater the amount of traffic affected by the action, the greater is the HC emissions reduction. It would seem that the percentage of Vmt that would be affected by road repair and maintenance activities on any given day would be small, say five percent. The potential speed increase for all periods would also seem to be small on an average day. For example, an increase of 2 mph for arterial peak traffic (average speed 11.9 mph) would

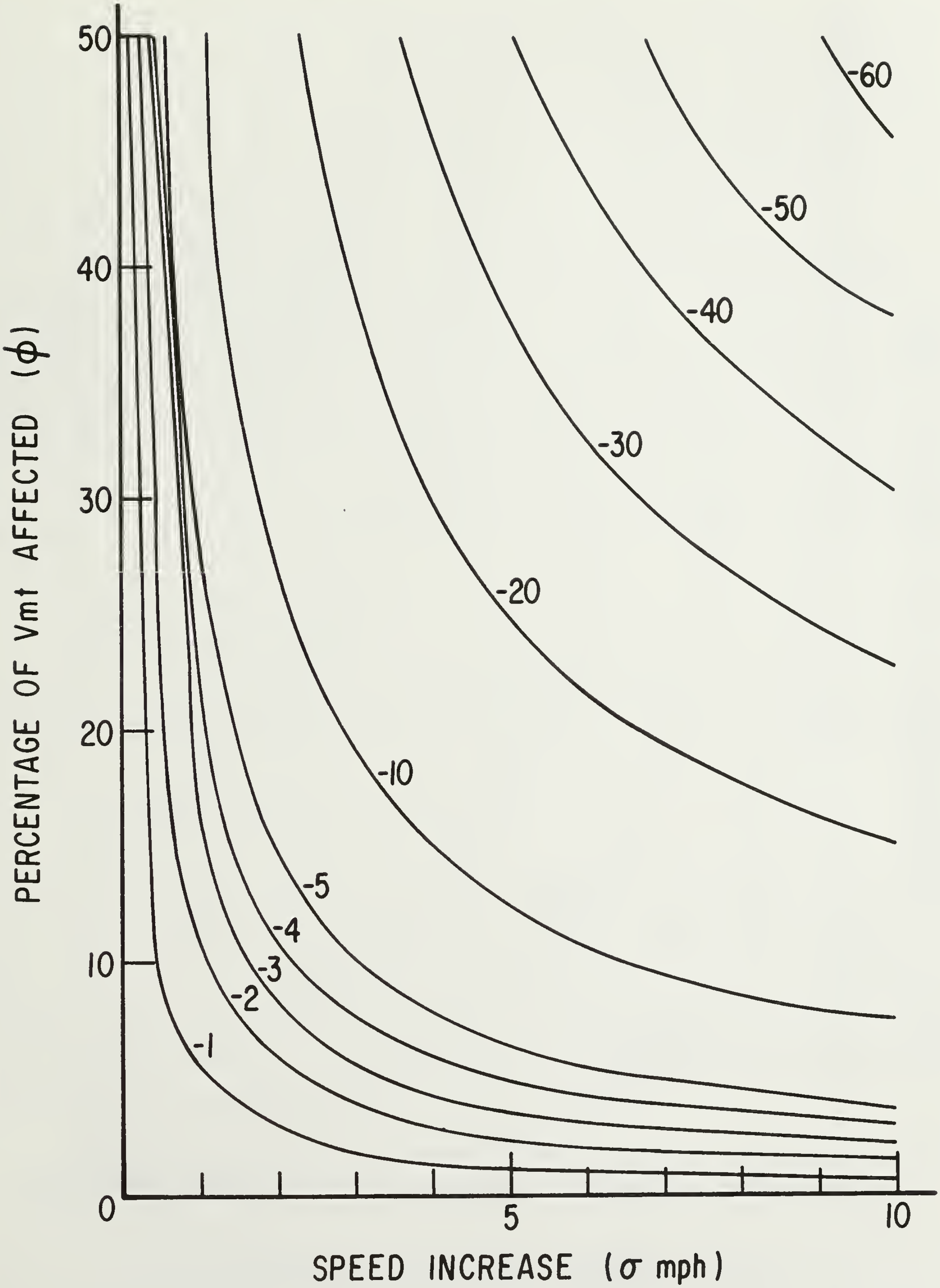

Fig. 11.1. HC Change due to Speed Increase from Limiting Road Repairs (tons/day)

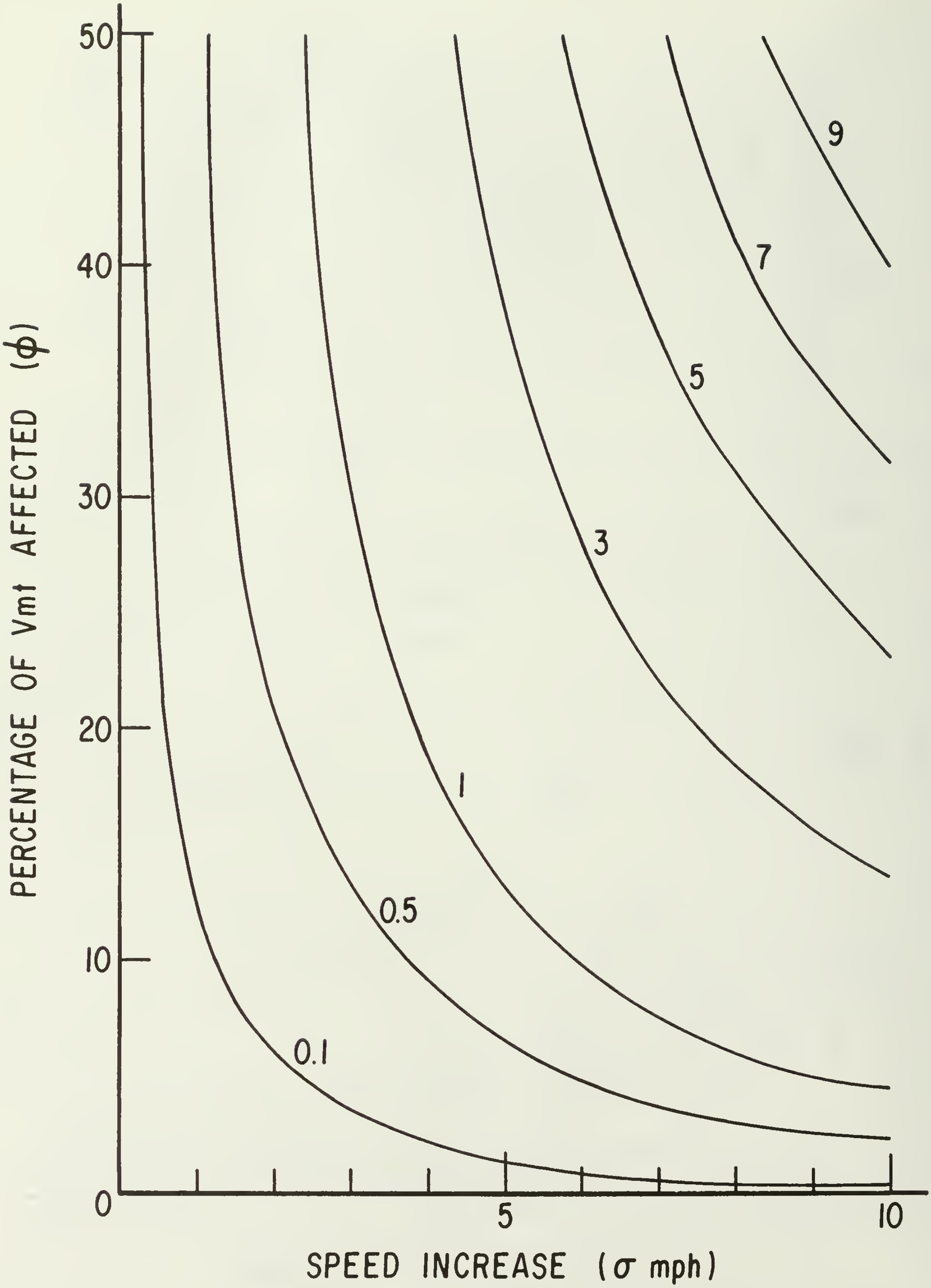

Fig. 11.2. NO_x Change due to Speed Increase from Limiting Road Repairs (tons/day)

be an increase of 17%, which is seemingly unlikely.* While it is conceivable that a large speed increase could occur if the start of a major construction project was postponed the day of an alert, the probability of such an event is very small; thus the expected impact on emissions of such an event is small, also. Figure 11.1 shows that an increase of 2 mph for five percent of the total Vmt results in a reduction of about 2.0 tons HC/day.

Illustrated in Fig. 11.2 is the effect of speed increases on NO_x emissions. For all speed increases and percentages of traffic affected, it appears that total NO_x emissions increase. (See Fig. E.2, which shows that NO_x emission factors increase at speeds above 15.0 mph). Again, assuming that the average speed of 5% of the Vmt is increased by 2 mph, NO_x emissions *increase* by approximately 0.1 tons/day, as shown in Fig. 11.2.

Based on Eq. 11.7, the emission reductions resulting from the action, assuming $\phi = 0.05$ and $\sigma = 2$, is then:

$R_1 = 2.0$ tons HC/day, and

$R_2 = -0.1$ tons NO_x/day.

The emission reductions for various length episodes, using the above assumptions, are provided in Table 11.1

11.3 SENSITIVITY ANALYSIS FOR ACTION 9

The delay cost estimate for Action 9 is based on an assumed percentage of delayable highway construction expenditures, α. However, the delay cost is a relatively small component of the total cost estimate of Action 9. Therefore, even if $\alpha = 1.0$ (which is extremely high) the total cost of a two-day episode would only increase by 12% (i.e., from \$16,000 to \$17,900). Similarly, the total cost estimates of Action 9 are relatively insensitive to the assumed value of α for episodes lasting 1, 3, 4, or 5 days.

The emission reductions expected from Action 9 are sensitive to the assumed speed increase, σ, and the assumed percentage of Vmt affected by

*This is an average speed increase for an entire trip. For the segment of the trip where the roadway would have been repaired the speed increase may be considerably higher. However, local effects are not being estimated; therefore, the average speed affect for the entire trip is appropriate.

delayed roadway repairs, ϕ. From Fig. 11.1 it can be seen that with σ = 2 mph ϕ would have to be greater than 15% before the HC emission reductions exceed 5.0 tons. Similarly, with $\phi = 0.05$, R_1 cannot exceed 5.0 tons. Therefore, for reasonable estimates of σ and ϕ, the HC emission reductions will not differ significantly from those presented in Table 11.1.

However, as σ, ϕ, and HC emission reductions increase, NO_x emissions *increase* as shown in Fig. 11.2. Therefore, increased reductions of HC emissions from Action 9 imply increased NO_x emissions. Therefore, if Action 9 is more effective in reducing HC than indicated, it is also more detrimental in terms of NO_x.

This discussion implies that the estimated impacts of Action 9 are not very sensitive to the data limitations of the analysis, i.e., the assumed values of α, ϕ, and σ.

11.4 REFERENCES

1. *Census of Governments, Local Government in Metropolitan Areas, 1972,* Vol. 5., Table 12, U.S. Bureau of the Census.

2. *State of Illinois Department of Transportation Proposed Improvement for Illinois Highways, Fiscal Year, 1975,* data obtained in phone conversation with staff from District 1 Offices of IDOT, Schaumburg, Ill. (1976).

12 CLOSING SELECTED STATIONARY POLLUTION SOURCES -- ACTION 10

During a red alert, manufacturing and other facilities with process pollutant sources that emit organic material (hydrocarbons) or nitrogen oxides in excess of: (1) 100 tons/year, or (2) 550 lbs/operating day, or (3) the Illinois emission standards, must curtail such emissions to the greatest extent possible (short of causing injury to persons or severe damage to equipment). Because data on facilities emitting more than 550 lbs of pollutants/operating day were not available, the analysis of Action 10 applies only to facilities satisfying conditions 1 and 3. Furthermore, information was not available on the degree to which certain industries can be closed down. Therefore, it is assumed that each firm affected is completely shut down during an episode. The costs and emission reduction effects of Action 10 are summarized in Table 12.1.

12.1 COSTS OF ACTION 10

The costs of Action 10 include those of (1) notifying the affected facilities and their employees of the red alert, (2) inventory or overtime to avoid lost production, (3) shutting down and starting up operations, (4) rescheduling operations, and (5) spoilage of perishable products. The data, methods, and assumptions used to estimate these costs are discussed below.

Notification Cost

The facilities required to curtail activities are assumed to be informed by telephone of the red alert and the actions required of them. Employees are assumed to be informed ahead of time of the actions they should take if a red alert is called. Therefore, radio and TV announcements would be sufficient to notify the employees of the affected industries.

Assuming each phone call lasts two minutes, the telephone notification costs are:

$$C = N \cdot (T + W/5040 + \overline{W}/5040) \tag{12.1}$$

where:

$C \equiv$ the telephone notification cost,

$N \equiv$ the number of facilities requiring notification,

Table 12.1. Summary of the Costs and Emission Reduction Effects of Closing Selected Stationary Pollution Sources[a]

Episode Length (days)	Costs ($\$10^3$) Notification	Inventory	Overtime	Shut-Down & Start-Up	Rescheduling	Spoilage	Total
1	6.93	0	5,160	392	26.4	29.9	5,620
2	13.7	0	7,730	392	39.6	59.8	8,240
3	20.5	0	8,540	392	52.9	89.8	9,100
4	27.3	0	12,900	392	66.1	120	13,500
5	34.1	0	15,500	392	79.3	150	16,200

Table 12.1. (Cont'd)

Episode Length (days)	HC Emission Reductions (tons)			NO_x Emission Reductions (tons)		
	Stationary Sources	Motor Vehicles	Total	Stationary Sources	Motor Vehicles	Total
1	617	23.4	640	88.4	9.50	97.9
2	1,230	46.8	1,280	177	19.0	196
3	1,850	70.2	1,920	265	28.5	294
4	2,470	93.6	2,560	354	38.0	392
5	3,080	117	3,200	442	47.5	490

[a]The inventory and overtime costs are functions of the expected frequency and duration of a red alert. If this action is used for a yellow alert, the inventory and overtime cost estimates will change. However, the above results are maximum costs of this action for alert stages called at ozone concentrations less than 0.3 ppm and are appropriate for all alert stages called at ozone concentrations greater than or equal to 0.3 ppm.

$T \equiv$ the cost of a telephone call,

$W \equiv$ the monthly wage rate of the person making the telephone call,

$\overline{W} \equiv$ the monthly wage rate of the person receiving the telephone call, and

The constant 5040 is the number of two-minute time periods in a working month (i.e., in 21 eight-hour days).

In 1974 there were about 189 sources in the Chicago area that emitted more than 100 tons of HC or NO_x per year, and seven sources with variances for

HC or NO_x [Ref. 2].* Therefore, N = 196. Assuming the telephone calls are made and received by lower level management personnel, $W = \overline{W} = \$1,416$ (the medium monthly salary of a Director of Personnel I; see Table A.5). Setting T = \$0.10 and substituting the above values of N, W, and $\overline{W}$ into Eq. 12.1 results in telephone notification costs of \$129.70.

The costs of the radio and TV announcements are \$6,800/day, as calculated in Appendix D. Assuming the telephone calls are only required on the first day of the episode, the total notification cost for an n-day episode is estimated as in Eq. 12.2; notification costs for episodes of various lengths are provided in Table 12.1.

$$\overline{C} = 6800 \cdot n + 129.7 \tag{12.2}$$

Inventory and Overtime Cost

It is assumed that, whenever possible, firms adjust operations to avoid production losses due to an episode. This may be done either by increasing inventories *prior* to the episode season or using overtime labor *after* an episode; either adjustment will assure that total production will not be affected by an episode. However, the natures of these adjustments are quite different. The inventory adjustment results in a cost whether an episode occurs or not, because inventories would be increased before an episode occurs. On the other hand, the overtime adjustment results in a cost only if an episode occurs. This distinction is quite important, as will be seen later in this section.

The costs of inventory adjustment are the capital finance charge associated with holding the additional inventory and the cost of storing and retrieving the additional inventories. It is assumed that sufficient storage capacity exists and no capital costs will be required for constructing additional storage facilities. These assumptions imply an inventory cost of:

$$\hat{C}(d) = \sum_{j \varepsilon J} \{[d \cdot U_j/365] \cdot [(1+i)^{\hat{T}} - 1] + W_j \cdot d \cdot \alpha\} \tag{12.3}$$

where:

$\hat{C} \equiv$ the increased inventory cost,

*These statistics were derived from data supplied by the Illinois Environmental Protection Agency. References are listed in Sec. 12.4.

$j \equiv$ Standard Industrial Classification (SIC),

$J \equiv$ the set of industries that uses the inventory option,

$d \equiv$ the number of lost production days made up using the inventory option,

$U_j \equiv$ the annual value of production in industry j,

$i \equiv$ the daily cost of capital,

$\hat{T} \equiv$ the number of days the extra inventory is held,

$W_j \equiv$ the daily wage rate of individuals in industry j who store and retrieve inventories,

$\alpha \equiv$ the number of man-days required to store and retrieve additional inventories equal to one day's production, and

The constant 1/365 converts the annual value of production to the average daily value of production.

The first term in Eq. 12.3 is the capital finance charge of holding additional inventories of $d \cdot U_j/365$; the second term, $W_j \cdot d \cdot \alpha$, is the storage and retrieval cost.

The overtime cost is estimated as:

$$\tilde{C}(\bar{d}) = \sum_{j \varepsilon \bar{J}} 0.5 \cdot \bar{W}_j \cdot 8 \cdot P_j \cdot \bar{d} \qquad (12.4)$$

where:

$\tilde{C}(\bar{d}) \equiv$ the overtime cost as a function of $\bar{d}$,

$\bar{d} \equiv$ the number of production days made up using the overtime option,

$\bar{J} \equiv$ the set of industries using the overtime option,

$\bar{W}_j \equiv$ the average hourly wage rate of production workers in industry j,

$P_j \equiv$ the number of production workers in industry j,

The constant 0.5 reflects the assumption that, on the average, the overtime rate for production workers is 1.5 times the normal wage rate, and

The constant 8 is the number of hours in a working day.

The first step in estimating inventory and overtime costs is to determine which industries will use each option, i.e., the sets J and $\bar{J}$. Some industries have production or inventory constraints which preclude them from using the inventory option; these constraints are:

- The product is perishable or cannot be inventoried,
- The product is produced to order and cannot be made until a customer orders it,

- A product is dated (e.g., a newspaper) and cannot be inventoried, or
- Production workers already are working more than 40 hours a week and overtime labor would be required to produce additional inventories. In this case, it will always be cheaper to use the overtime option.

Nine industries have been identified that fall into one or more of these categories: those that manufacture meat products (201),* dairy products (202), newspapers (271), periodicals (272), commercial printing products (275), petroleum and coal products (29), primary metals (33), and fabricated metals (34); and non-manufacturing facilities such as dry cleaners (721).

The goods produced by industries 201 and 202 are perishable and many non-manufacturing industries affected by the action cannot inventory their outputs. Newspaper and periodicals cannot be inventoried because they are dated. Since the output of commercial printers cannot be separated into the value of items that can be inventoried, it is assumed that all the output is made to order and cannot be inventoried. The SICs 29, 33, and 34 are reported to have had average work weeks per production worker of more than 40 hours for both 1972 [Ref. 5] and 1973.** For these industries, overtime labor would be required to make up for lost production due to an episode; Table 12.2 shows the wages ($\overline{W}_j$) and number of production workers (P_j) in the Chicago SMSA in such industries. Assuming that one day is required to resume production after an episode, i.e., $\overline{d} = n + 1$ where n is the length of an episode, and substituting the 1974 $\overline{W}_j$ and P_j values from Table 12.2 into Eq. 12.4 results in the overtime costs in affected industries with inventory constraints shown in Table 12.3.

For all other industries the inventory or overtime option can be used, with the choice depending on the relative costs of the two options. If an episode occurs, the inventory option will usually be cheaper than the overtime option. However, inventories must be built up in advance of the episode season. If an episode does not occur during a given year or the duration of

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*Number indicates Standard Industrial Classification (SIC).

**The 1973 average weekly hours worked were calculated from the number of production workers and number of production worker man-hours reported in Ref. 1.

Table 12.2. Average Wages and Number of Production Workers in Chicago SMSA in Industries with Constraints to the Inventory Adjustment

	Average Wages, W_j ($/hr)		1973 Employment[a]			1974 Employment in Large Polluting Firms Using Overtime[c,d]	
SIC	1973[a]	1974[b]	Total Workers	Production Workers	% Prod. Workers	Total Workers	Production Workers, P_j
20	4.57	5.07	72,300	51,100	70.7	550	389
27	5.58	6.19	85,000	52,200	61.4	14,959	9,187
29	5.27	5.85	6,200	4,300	69.4	2,990	2,074
33	5.39	5.98	60,900	49,300	81.0	13,725	11,111
34	4.62	5.13	114,200	89,300	78.2	15,398	12,040
721	--	5.00[e]	--	--	--	300	300

[a]*Annual Survey of Manufactures: 1973*, U.S. Department of Commerce, M73(A)-6 (1976).

[b]Adjusted based on consumer price index; see Table A.6.

[c]From IEPA Emission Inventory [Ref. 2] and Illinois Manufacturers Directory [Ref. 6].

[d]It is assumed that the proportions of production workers to total employees for each industry, as listed in the sixth column, are applicable to the large polluters.

[e]Estimate.

Table 12.3. Cost of Overtime Adjustments for Industries with Inventory Constraints

Episode Length (days)	Costs by Standard Industrial Classification ($$10^3$)						
	201,202	271, 272,275	29	33	34	721	Total
1	15.78	454.9	97.06	531.6	494.1	12.0	1605
2	23.67	682.4	145.6	797.3	741.2	18.0	2408
3	31.56	909.9	194.1	1063	988.2	24.0	3211
4	39.44	1137	242.7	1329	1235	30.0	4013
5	47.33	1365	291.2	1595	1482	36.0	4816

an episode is less than expected, then inventory costs may be greater than overtime costs. For this reason, each firm would select an inventory/overtime strategy based on the cost of holding inventories and the expected frequency and duration of red alerts.

Good estimates of the frequency and duration of red alerts are not available. However, the IEPA has made some preliminary estimates [Ref. 3]. It is estimated that the expected frequency of ozone concentrations in the Chicago area reaching 0.30 ppm, i.e., red alert levels, is once every two years or 0.5 times a year. Furthermore, the number of times and number of days that meteorological conditions are such that a red alert *could* occur during a five-year period are: one-day period, 11 times; two-day period, 6 times, and five-day period, 0 times [Ref. 3]. Assuming that (1) the likelihood of one-, two-, and five-day episodes are proportional to the likelihoods of meteorological conditions that could result in a red alert and that (2) the number of occurrences of meteorological conditions to support a three- or four-day red alert in a five-year period are six and one, respectively, then the likelihoods of a red alert lasting 1 to 5 days in a year are 0.262, 0.143, 0.071, 0.024, and 0.0, respectively. For example, the likelihood of a three-day red alert occurring in a year is estimated to be: $0.5 \cdot [3/(11 + 6 + 3 + 1 + 0)] = 0.071$.

To determine the inventory/overtime strategy, a firm will solve the following equation for d, i.e., the level of increased inventories:

$$\min \quad \hat{C}(d) + \sum_{n=1}^{5} \tilde{C}(\bar{d}) \cdot L_n \tag{12.5}$$

$$\text{s.t.} \quad \bar{d} = n + 1 - d$$

$$\bar{d} \geq 0, \text{ if } \bar{d} < 0 \text{ set } \bar{d} = 0$$

$$d \geq 0$$

where:

$\hat{C}(d) \equiv$ the cost of increasing inventories by d days of production,

$\tilde{C}(\bar{d}) \equiv$ the cost of overtime labor for $\bar{d}$ days, and

$L_n \equiv$ the likelihood over a one-year period of a red alert lasting n days.

The constraint that $\bar{d} = n + 1 - d \geq 0$ assumes that additional inventories will be depleted before overtime labor is used if an episode occurs.

Before the optimal values of d can be estimated, the inventory cost as determined by Eq. 12.3, must be estimated. To estimate this cost, i, the daily cost of capital, is set equal to $2.611 \cdot 10^{-4}$, which is equivalent to an annual cost of capital of 10%. Since the ozone season lasts from April to September, $\hat{T} = 182$ days, i.e., half a year. Furthermore, it is assumed that two man-days ($= \alpha$) are required to store and retrieve a day's worth of production stored in inventory. Assuming W_j = \$40/day (\$5/hr), Eq. 12.3 becomes:

$$\hat{C}(d) = d \cdot \sum_{j \varepsilon J} (1.3332 \cdot 10^{-4} \cdot U_j + 80)$$

$$= d \cdot [1.3332 \cdot 10^{-4} \cdot (\sum_{j \varepsilon J} U_j) + 128 \cdot 80] \qquad (12.6)$$

The variable U_j is set equal to the annual value added by manufacturing in industry j. The set J includes all large polluting firms affected by Action 10 that do not have inventory or production constraints that preclude them from using the inventory option; the constant 128 reflects the fact that there are 128 such firms.

The value added by manufacturing in the firms affected by Action 10 is unknown. To estimate U_j, the value added by *all* manufacturing in the Chicago SMSA (see Appendix C) is allocated to each two-digit SIC industry affected by Action 10 (see list in Table 12.8) in proportion to:

- The fraction of employees in the affected firms in each two-digit SIC industry relative to total employment in each two-digit SIC industry, and
- The fraction of the sum of the emissions of HC and NO_x in the affected firms relative to the sum of total HC and NO_x emissions by firms emitting more than 25 tons/year of HC or NO_x.

Because the firms affected by Action 10 are generally the larger ones in each industry, and larger firms in a given industry tend to be less labor intensive (i.e., have a higher capital/labor ratio), the apportionment based on employment most likely underestimates the actual value added in the affected firms. Since the affected firms are the heaviest polluters in each industry, the value added estimates based on emissions probably are overestimates. Therefore, the average of the two procedures is used to obtain a reasonable estimate of the value added in the firms affected by Action 10.

Table 12.4 summarizes the data used to apportion the total value added data. The resulting estimates of the value added in the firms affected by

Table 12.4. Value Added in Large Polluting Industry, 1974

SIC	1974 Employment: Total No. in SMSA[a]	No. in Large Sources[b]	% in Large Sources	1974 Value Added (10^6): SMSA Total[c]	Large Sources, Employment Method	Large Sources, Emission Method[d]
20	71,803	6,643	9.25	2,085.6	192.95	1,991.33
22	3,269	948	29.00	63.8	18.50	60.92
23	20,654	58	0.28	282.8	0.79	270.02
24	5,800	316	5.45	134.0	7.30	127.94
25	16,288	3,561	21.86	329.7	72.07	314.80
26	33,155	4,666	14.07	663.1	93.32	633.13
27	86,240	15,139	17.55	1,952.2	342.70	1,863.96
28	41,088	13,876	33.77	1,750.6	591.20	1,671.47
29	6,302	2,990	47.45	382.9	181.67	365.59
30	33,165	1,722	5.19	488.4	25.36	466.32
32	22,585	2,211	9.79	444.2	43.49	424.12
33	60,385	13,725	22.73	1,329.2	302.12	1,269.12
34	118,345	15,398	13.01	2,326.1	302.65	2,220.96
35	130,375	11,993	9.20	2,523.2	232.11	2,409.15
36	134,683	36,229	26.90	2,832.3	761.87	2,704.28
37	30,542	24,913	81.57	856.2	698.40	817.50
38	29,146	12,792	43.89	786.9	345.37	751.33
39	31,927	2,927	9.17	512.9	47.02	489.72
TOTAL	875,752	170,107	19.42	19,744.1	4,258.89	18,851.67

[a] From Table A.3.

[b] Illinois air pollution emission inventory [Ref. 2] and the Illinois Manufacturing Directory [Ref. 6]. Firms with missing information were assigned average values.

[c] From Table C.2.

[d] 95.48% of total value added. This is the percentage of HC and NO_x emissions from large sources.

Action 10 using the employment and emission allocation procedures are provided in the two right-hand columns of Table 12.4.

To obtain the values of U_j, i.e., the values added in the affected firms that can use the inventory adjustment option, the proportion of the value added attributed to those firms that are assumed to have inventory or production constraints must be subtracted from the values given in Table 12.4. From the employment data for the large polluting industries provided in Tables 12.2 and 12.4, it can be seen that $100 \cdot (6{,}643 - 550)/6{,}643 = 91.72\%$ of the food and kindred (SIC 20) industry and $100 \cdot (15{,}139 - 14{,}959)/15{,}139 = 1.119\%$ of the printing (SIC 27) industry can use the inventory option if the employment apportionment is used. If the emission option is used these percentages are 89.3% and 2.00%, respectively. Applying these percentages for SIC 20 and 27, and assuming that none of the output from SIC 29, 33, and 34 can be inventoried, results in the estimates of U_j presented in Table 12.5. For example, for SIC 20 and the employment apportionment scheme, the value added is: $U_{20}(\text{emp}) = 0.9172 \cdot (192.95 \cdot 10^6) = \$176.97 \cdot 10^6$.

Substituting the values of U_j in Table 12.5 into Eq. 12.6 results in, for the employment method:

$$\hat{C}(d)_{\text{emp}} = (415{,}672 + 10{,}240) \cdot d = \$425{,}912 \cdot d \tag{12.7}$$

and, for the emission method:

$$\hat{C}(d)_{\text{emn}} = (1{,}727{,}325 + 10{,}240) \cdot d = \$1{,}737{,}565 \cdot d \tag{12.8}$$

Since these two methods bound the inventory cost, a combined method using the average of the two will also be considered, i.e.:

$$\hat{C}(d)_{\text{com}} = (1{,}071{,}499 + 10{,}240) \cdot d = \$1{,}081{,}739 \cdot d \tag{12.9}$$

Using adjusted hourly wage rates for production workers in all SICs, and estimating the number of production workers in the firms affected by Action 10,* the overtime cost is estimated to be, from Eq. 12.4:

$$\tilde{C}(\bar{d}) = \$1{,}774{,}904 \cdot \bar{d} \tag{12.10}$$

Equations 12.7 through 12.10 are used in Eq. 12.5 to obtain the best value of d on an aggregated basis. It is assumed that this value is optional

*The firms that have inventory production constraints are excluded to avoid double counting.

Table 12.5. Annual Value Added by Firms Affected by Action 10 that Can Use the Inventory Option

SIC	Annual Value Added, U_j ($\$10^6$) Employment Method	Emission Method
20	176.97	1,778.26
22	18.50	60.92
23	0.79	270.02
24	7.30	127.94
25	72.07	314.80
26	93.32	633.13
27	4.08	37.28
28	591.20	1,671.47
29	0	0
30	25.36	466.32
32	43.49	424.12
33	0	0
34	0	0
35	232.11	2,409.15
36	761.87	2,704.28
37	698.40	817.50
38	345.37	751.33
39	47.02	489.72
TOTAL	3,117.85	12,956.24

for all the firms in J. Recall that it was estimated that L_n = 0.262, 0.143, 0.071, 0.024 and 0.0 for n = 1 to 5, respectively. Substituting Eq. 12.7, 12.8, or 12.9; Eq. 12.10; and the above values of L_n into Eq. 12.5 results in the values of $\hat{C}(d)$ presented in Table 12.6.

As indicated in Table 12.6, no inventorying would be used with either the combined or emission value added allocation scheme. If the employment allocation scheme is appropriate, then, on the average, only two days worth of production would be inventoried in the firms affected by Action 10. Since (1) the combined method is the best estimate; (2) the values of L_n are conservative, i.e., they reflect maximum likelihood; and (3) the smaller the values of L_n, the less attractive the inventory adjustment becomes, it is assumed that none of the industries affected by Action 10 will use the

Table 12.6. Optimal Inventory/Overtime Schemes

Additional Days of Inventory	Expected Annual Cost ($\$10^3$) Inventory	Overtime	Total
Employment Method			
0	0	2,409	2,409
1	425.9	1,521	1,947
2[a]	851.8	633.6	1,485
3	1,278	211.2	1,489
4	1,704	42.60	1,747
5	2,130	0	2,130
6	2,556	0	2,556
Emission Method			
0[a]	0	2,409	2,409
1	1,738	1,521	3,259
2	3,475	633.6	4,109
3	5,213	211.2	5,424
4	6,950	42.60	6,993
5	8,688	0	8,688
6	10,425	0	10,425
Combined Method			
0[a]	0	2,409	2,409
1	1,082	1,521	2,603
2	2,163	633.6	2,797
3	3,245	211.2	3,456
4	4,327	42.60	4,370
5	5,409	0	5,409
6	6,490	0	6,490

[a]Optimal value of additional days of inventory, d.

inventory option, i.e., d = 0 for all firms. Using this assumption, the inventory cost is zero and the overtime cost for an n-day episode is:

$$\tilde{C}' = 1{,}774{,}904 \cdot (n + 1) + \tilde{C}_n \qquad (12.11)$$

where $\tilde{C}_n$ are the overtime costs in Table 12.3. Table 12.7 provides estimates of $\tilde{C}'$ by SIC for one day of overtime. The values of $\tilde{C}'$ for episodes of various lengths are provided in Table 12.1.

Table 12.7. Overtime Cost of Action 10 by SIC

SIC	Cost ($\$10^3$/day)
20	95.89
22	12.79
23	0.67
24	4.27
25	48.00
26	64.66
27	230.19
28	151.56
29	48.53
30	21.31
32	33.00
33	265.80
34	247.05
35	191.51
36	481.10
37	465.65
38	172.42
39	37.86
721	6.00
TOTAL	2,578.00

Shut-Down and Start-Up Cost

Unlike most retail or service businesses, many manufacturing firms cannot simply be closed and left unattended when production is stopped. Furnaces often must be allowed to cool slowly, materials must be stored, security personnel must be kept on duty, etc. The shut-down and start-up procedures most likely vary greatly among firms within industrial groups and among industries. As a result, the costs of shutting down and starting up production processes vary greatly.

Unfortunately, data on these costs are not available. For this analysis, it is assumed that for the larger firms an average of \$2,000 is required to shut down and start up operations. Therefore, for the 196 firms affected by Action 10, the shut-down and start-up cost would be: 196 • \$2000 = \$392,000. This cost is assumed to be independent of the length of the episode, as indicated in Table 12.1.

Rescheduling Cost

Production schedules must be changed to adjust to an episode. Assuming that one man-day of rescheduling is required per large firm affected per day lost due to an episode, then the rescheduling cost for an n-day episode is:*

$$\underline{C} = N \cdot W/21 \cdot (n + 1) \qquad (12.12)$$

where:

$\underline{C} \equiv$ the rescheduling cost,

$N \equiv$ the number of firms requiring rescheduling,

$W \equiv$ the monthly wage rate of the person doing the rescheduling, and

The constant 21 is the number of working days in a month.

The value of N is 196. Assuming lower level management personnel do the rescheduling, then W = 1,416 (see Table A.5, Director of Personnel I medium income). Substituting these values of N and W into Eq. 12.12 results in the rescheduling cost shown in Table 12.1.

Spoilage Cost

Most manufacturing products are not perishable. However, if production is stopped in food and kindred industries, some products may spoil. There are no data available on spoilage; however, it is reasonable to conclude that with refrigeration, a short delay in production will result in little spoilage of input or final products. Since there is the likelihood of some spoilage, it is assumed that one percent of the value of the food products produced each day might spoil, i.e., the spoilage cost is: $29,922/day = $(1,092.1 \cdot 10^6/365) \cdot 0.01$.** This spoilage cost is shown in Table 12.1.

12.2 EMISSION REDUCTION EFFECTS OF ACTION 10

The effectiveness of Action 10 is estimated as:

$$R_p = A_p + B_p + G_p \qquad (12.13)$$

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*It is assumed that the number of production days lost is one more than the number of days of the episode.

** The annual value added in food and kindred industries (SIC 20) affected by Action 10 is estimated to be $(192.95 + 1,991.33) \cdot 10^6/2 = 1,092.1 \cdot 10^6$ (see Table 12.4).

where:

R_p ≡ emission reduction of pollutant p (tons/day);

p ≡ pollutant: 1 = hydrocarbons, and 2 = nitrogen oxides;

A_p ≡ emission reduction of pollutant p due to the curtailment of facility operations (tons/day);

B_p ≡ emission reduction of pollutant p due to the curtailment of production workers' work trips (tons/day); and

G_p ≡ emission reduction of pollutant p due to reduced sales of gasoline (tons/day).

The variable A_p is calculated as follows:

$$A_p = \sum_{f=1}^{N} E_{fp}/365 + \sum_{v=1}^{N'} E'_{vp}/365 \qquad (12.14)$$

where:

f ≡ facilities emitting more than 100 tons/year of either HC or NO_x;

E_{fp} ≡ annual emission rate of pollutant p by facility f (tons/year);

v ≡ facilities having HC or NO_x variances and emitting less than 100 tons/year;

E'_{vp} ≡ annual emission rate of pollutant p by facility v (tons/year); and

The constant 365 is the number of days in a year.

The variable B_p is calculated as follows:

$$B_p = \sum_{j=1}^{4} V_j \cdot E^*_p(S_j)/907{,}184 + \sum_{j=1,3} \sum_{i=1}^{9} \overline{V}_{ij} \cdot [\overline{E}_{pi}(S_j) - \overline{E}_{pi}(S'_j)]/907{,}184 \qquad (12.15)$$

where:

j ≡ traffic segment: 1 = expressway peak, 2 = expressway off-peak, 3 = arterial peak, and 4 = arterial off-peak;

V_j ≡ passenger auto Vmt during period j by production workers driving to and from work (miles/day);

$E^*_p(S_j)$ ≡ emission rate of pollutant p at average speed S_j before the action for passenger autos (grams/mile);

i ≡ vehicle class (see Appendix E);

$\overline{V}_{ij}$ ≡ Vmt of class i vehicles during traffic segment j, after the action (miles/day). The Vmt of all vehicle classes after the action will be the same as before the action except for passenger autos;

$\bar{E}_{pi}(S_j)$ ≡ emission rate of pollutant p for vehicle class i at average speed S_j before the action (grams/mile);

$\bar{E}_{pi}(S_j')$ ≡ emission rate of pollutant p for vehicle class i at average speed S_j' after the action (grams/mile); and

The constant 1/907,184 converts grams to tons.

The first term in Eq. 12.14 represents emissions from facilities, excluding incinerators and electric utility power plants, that emit more than 100 tons annually of HC or NO_x. Emissions from additional facilities having HC or NO_x variances are represented by the second term. The first term in Eq. 12.15 represents the emission reduction due to the associated traffic curtailment. It is assumed that only production workers' trips are curtailed and that no substitute trips are made. The emission change due to the speed increase caused by the traffic reduction is represented by the second term in the equation.

Two underlying assumptions are embodied in this formulation. First, annual emissions are divided by 365 to obtain average daily emissions. Since some industries may experience yearly production cycles in which more (or less) activity occurs during the summer months than the rest of the year, the calculated average daily emissions could be an underestimate (or overestimate) of the actual amount. The assumption is made that facilities producing emissions at a higher rate during the summer months balance facilities producing emissions at a lower rate, and, therefore, the total average daily emission estimates would be fairly accurate.

Second, the *total* emissions of every facility emitting more than 100 tons per year or having a variance are included in the effectiveness calculation. Here, it is assumed that every firm affected completely curtails its production activities. In this regard Eq. 12.14 produces a slight overestimate of emission reductions due to the action. Also, the portions of emissions at each facility due to industrial processes, fuel combustion, and incineration cannot be determined from the available data. Since incineration operations would not be curtailed by this action, the use of Eq. 12.14 again results in an overestimate of emission reductions due to the action.

Thus, it would seem that, taking all of these assumptions into consideration, the emission reductions are overestimates.

An emission inventory obtained from the Illinois EPA [Ref.2] includes annual emissions for all stationary sources in the Chicago SMSA emitting more than 25 tons/year of any one of the five major air pollutants: hydrocarbons, nitrogen oxides, sulfur dioxide, particulate matter, and carbon monoxide.* To evaluate the effectiveness of this action, the inventory was screened for facilities emitting more than 100 tons per year of HC or NO_x, excluding electric utility power plants and incinerators, which would not be affected by the action. The remaining facilities can be broken down into three groups: (1) manufacturers, (2) dry cleaners, and (3) commercial and other sources, such as office buildings, housing projects, etc. Emissions in the first group are probably due mainly to industrial processes and fuel combustion. Dry cleaners' emissions are primarily HC from cleaning operations. The major portion of emissions from the third group is most likely from fuel combustion, as evidenced by the large amounts of NO_x relative to HC emitted by this group (see Table 12.8).

The total emissions from facilities emitting more than 100 tons per year of HC or NO_x are presented in Table 12.8, which groups facilities engaged in manufacturing by type of industry. Less than 2% of the emissions is produced by facilities which cannot be classified by SIC code; the emissions from these facilities are distributed among industrial groups in proportion to the emissions generated by each group.

Total emissions of facilities emitting more than 100 tons per year of NO_x or HC from Table 12.8, based upon Eq. 12.14, are 88.4 tons NO_x/day and 616 tons HC/day. In addition, seven facilities having HC variances were estimated to emit 0.6 tons HC/day and no NO_x.** No facilities were found to have

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*The emissions inventory was established from data collected in 1971. Since that time, sources were updated as new information became available. Thus, the inventory contains data collected between 1971 and 1976, with some estimates probably being outdated. It is assumed that all data is for 1974.

**A list of facilities with HC and NO_x variances was obtained from the Illinois EPA [Ref. 2]. The emissions of these facilities were determined by matching the name of the plant on the variance list to the name on the emission inventory. For those facilities on the variance list which were not listed on the emission inventory, it was assumed that emissions were 25.0 tons per year of the pollutant for which the variance was granted. It was known that only one point source within each of these facilities emitted more than 25.0 tons per year. If these facilities emitted significantly more than 25.0 tons per year they would have appeared on the emission inventory. Thus, the 25.0 ton per year figure for these facilities appears to be a good estimate.

Table 12.8. Process and Fuel Combustion Sources Emitting More than 100 Tons/Year of NO_x or HC

Source and SIC	Total Emissions (tons/day) HC	NO_x
Manufacturing		
Food and kindred products (20)	20.41	1.07
Textile mill products (22)	5.98	0
Apparel (23)	0.40	0
Lumber and wood products except furniture (24)	10.34	0
Furniture and fixtures (25)	10.03	0.04
Paper and allied products (26)	119.04	1.24
Printing, publishing, and allied industries (27)	68.63	5.15
Chemicals and allied products (28)	87.09	12.78
Petroleum refining and related industries (29)	111.11	7.52
Rubber and miscellaneous plastics products (30)	19.96	0.74
Stone, clay, and glass products (32)	0.71	0.53
Primary metal industries (33)	6.41	37.08
Fabricated metal products (34)	80.52	2.65
Machinery, except electrical (35)	22.15	1.33
Electrical machinery, equipment and supplies (36)	7.53	1.61
Transportation equipment (37)	16.17	3.47
Measuring, analyzing, and controlling instruments (38)	12.45	0.30
Miscellaneous manufacturing (39)	4.10	0.02
Dry Cleaning	7.18	0.05
Other sources besides incinerators and power plants (office buildings, housing projects, etc.)	6.24	12.83
TOTAL EMISSIONS	616.45	88.41

NO_x variances which were emitting less than 100 tons per year of NO_x or HC. Thus, the stationary source emissions reductions due to this action, bearing in mind the previously stated assumptions, are estimated to be:

A_1 = 616 + 0.6 = 616.6 tons HC/day, and

A_2 = 88.4 tons NO_x/day.

Additional emission reductions result when workers in manufacturing curtail their work trips. As discussed in Appendix E, out of a total passenger auto Vmt of 82,842,500 miles per day, 7.9%, 1.4%, 22.6% and 4.0% consists of work Vmt during the expressway peak, expressway off-peak, arterial

peak and arterial off-peak traffic segments, respectively. Out of an estimated total of 2,886,841 employees in the SMSA, 121,808 or 4.22% are production workers and are employed in facilities affected by Action 10.* It is assumed that manufacturing work trip Vmt is the same percentage of total work Vmt as manufacturing workers are of total workers. Thus estimates of work trip Vmt by production workers (V_j in Eq. 12.15) are:

$$V_1 = 82{,}842{,}500 \cdot 0.079 \cdot 0.0422 = 276{,}180 \text{ miles/day}$$
$$V_2 = 82{,}842{,}500 \cdot 0.140 \cdot 0.0422 = 489{,}433 \text{ miles/day}$$
$$V_3 = 82{,}842{,}500 \cdot 0.266 \cdot 0.0422 = 790{,}085 \text{ miles/day}$$
$$V_4 = 82{,}842{,}500 \cdot 0.040 \cdot 0.0422 = 139{,}838 \text{ miles/day}$$

Applying passenger auto emission factors from Tables E.4 and E.5 to the above Vmt estimates, as in Eq. 12.15, the emission reductions due to work trip curtailment are 12.4 tons HC/day and 8.11 tons NO_x/day.

From the Vmt data of Table 12.9, it is estimated that the average speed of arterial peak traffic will increase from 11.9 mph to 13.0 mph; expressway peak traffic speed will increase from 43.7 mph to 44.3 mph. Emission factors for all vehicle classes are calculated at these new average speeds and used to estimate the speed increase effect from Eq. 12.15. The resulting emission reductions from the speed increases are 10.2 tons HC/day and 1.39 tons NO_x/day. The emission reductions, B_p, due to curtailment of production workers' work trips are:

$$B_1 = 12.4 + 10.2 = 22.6 \text{ tons HC/day, and}$$

$$B_2 = 8.11 + 1.39 = 9.50 \text{ tons } NO_x\text{/day.}$$

The evaporative hydrocarbon emission reduction due to the reduced average sale of gasoline, G_1, is estimated in Appendix G to be 0.790 tons HC/day. The value of G_2 is equal to zero. Therefore, the total emission reductions due to the action are estimated to be:

$$R_1 = 617 + 22.6 + 0.790 = 640 \text{ tons HC/day, and}$$

$$R_2 = 88.4 + 9.50 = 97.9 \text{ tons } NO_x\text{/day.}$$

*The 1971 employment for the SMSA was 2,841,659 (see Table A.2). This was adjusted to 1974 assuming employment is proportional to population. The number of production workers affected by Action 10 is obtained from total employment in Table 12.4 (the percent of production workers is calculated from data in Ref. 1). To this figure is added the number of employees in dry cleaning operations affected by Action 10.

Table 12.9. Speed Increase Data

Traffic Segment	Vmt before Action (miles/day)	Vmt After Action (miles/day)	Vmt/Hour After Action	Average Speed After Action[a] (mph)
Expressway Peak	7,451,000	7,174,820	1,434,964	44.3
Arterial Peak	21,393,000	20,602,915	4,120,583	13.0

[a]Based on peak speed adjustment equations (Appendix F).

12.3 SENSITIVITY ANALYSIS FOR ACTION 10

The estimated cost of shutting down and starting up operations, rescheduling operations, and spoilage are all estimated with little or no information. However, more than 91.8% of the total cost of a one-day episode and 95.6% of a four-day episode are due to overtime costs, which are extensively analyzed. Therefore, the lack of information on shut-down/start-up, rescheduling, and spoilage costs has little effect on the estimated total cost of Action 10.

12.4 REFERENCES

1. *Annual Survey of Manufactures, 1973,* U.S. Department of Commerce, M73(AS)-6 (1976).

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4. *County Business Patterns, 1973: Illinois,* U.S. Department of Commerce, Illinois (1974).

5. *Employment and Wages in States and Areas: 1939-1974,* U.S. Bureau of Labor Statistics (1975).

6. *Illinois Manufacturers Directory,* Manufacturers' News, Inc., Chicago (1974).

13 REQUIRED ELECTRIC POWER STATION EMISSION REDUCTIONS THROUGH SYSTEM WIDE ADJUSTMENTS, REDUCED SALES, AND PURCHASES OF POWER -- ACTION 11

During a red alert, electric power generating stations burning fossil fuels are required to reduce emissions in and into the affected area to the greatest extent practicable by adjusting operations system wide, discontinuing power generation for economy sales and service to interruptible customers, and maximizing purchase of available power.

Electric utilities can reduce emissions in the affected area by switching generation to plants outside the area or by using natural gas in plants having a dual fuel capability. Because emission reductions are required, it is assumed that both the load and fuel switching options will be used. Decreased sales and the purchase of power reduce the required amount of electricity to be generated; the reduction in electricity generation is treated parametrically by reducing generation by 0 to 25% of the total expected demand.

Because of the complexity of the options available to power companies, a computer program is used to simulate possible load and fuel switching options. Details of the program, which calculates the costs and emissions of alternative loading patterns and demand schedules, are presented in Appendix B. The resulting costs and emission reduction effects of Action 11 -- assuming both load and fuel switching and a six percent reduction in generation from curtailed economy/interruptible sales and purchasing power -- are summarized in Table 13.1 (on the next page).

13.1 COSTS OF ACTION 11

The costs of Action 11 include (1) the cost of notifying the power company of the red alert, (2) increased operating costs resulting from load and fuel switching, and (3) costs associated with reduced electricity generation. The data and assumptions used to estimate these costs are discussed below.

Notification Cost

The power company is assumed to be notified of a red alert by telephone. Assuming the call lasts two minutes, the notification cost is estimated to be:

$$C = N \cdot (T + W/5040 + \overline{W}/5040) \qquad (13.1)$$

Table 13.1. Summary of the Costs and Emission Reduction Effects of Required Restraints on Electric Power Plant Operations[a]

Episode Length (days)	Costs ($\$10^3$) Notification	Power Plant Oprtn.[b]	Buying Power	Interruptible and Economy Customers	Total	Emission Reductions (tons) HC	NO_x
1	0.010	26.3	396	84.2	506	4.86	163
2	0.020	52.7	792	168	1010	9.72	326
3	0.030	79.0	1190	253	1520	14.6	490
4	0.040	105	1580	337	1920	19.4	653
5	0.050	132	1980	421	2530	24.3	816

[a]Assuming both load and fuel switching and a six percent reduction in generation from curtailed economy/interruptible sales and purchasing of power.

[b]Includes load and fuel switching costs and operating cost savings from reduced electricity generation.

where:

$C \equiv$ the notification cost,

$N \equiv$ the number of power plants notified,

$T \equiv$ the cost of a telephone call,

$W \equiv$ the monthly wage rate of the person making the telephone call,

$\overline{W} \equiv$ the monthly wage rate of the person receiving the telephone call, and

The constant 5040 is the number of two-minute time periods in a working month (i.e., in 21 8-hour days).

Since there is only one power company, only one call is required. However, it is possible that each fossil fuel power station will have to be notified. If this occurs, then 12 calls will be made to the power company. Each interruptible/economy customer must also be notified of electricity curtailments. Since there are three of these customers, 15 telephone calls will be required. The value of T is set equal to \$0.10. The telephone calls are assumed to be made and received by lower level management employees. It is assumed that the median monthly income of a Director of Personnel I, \$1,416,* is the average wage rate for all lower level managers in the Chicago SMSA. Therefore, $W = \overline{W} = \$1,416$.

*See Table A.5.

Substituting these values of N, T, W, and $\overline{W}$ into Eq. 13.1 results in an estimated notification cost of $9.93. Notification is assumed to be made each day of the episode. The notification costs for various length episodes are presented in Table 13.1.

Operating Cost

The load and fuel switching costs are estimated by loading fossil fuel power plants outside of the Chicago SMSA before those within the area, and using natural gas to the greatest extent possible in the Chicago SMSA plants. Four steam plants are located outside the Chicago SMSA: Dixon, Kincaid, Powerton, and Sabrooke. In the Chicago SMSA the Waukegan Units 5, 6, 7, and 8; Ridgeland Units 1, 2, 3, and 4; Fisk Unit 19; Crawford Units 6, 7, and 8; and Joliet Units 7 and 8 can switch to natural gas.

Using the standard day with a peak demand of 11,500 MWh, as discussed in Appendix B, the costs of load and fuel switching in each plant, shown in Table 13.2, are calculated. The difference between the cost with and without an episode is the cost (in 1976 dollars) of load and fuel switching assuming no reduction in electricity generation relative to the standard day. This cost in 1974 dollars is $325,362. Table 13.3 shows the cost of load and fuel switching with reductions in electricity generation of 0, 6, 10, 20, and 25%. For electricity generation reductions greater than 6.5% there is an operating cost saving, which is the net effect of increased operating costs due to load and fuel switching and savings due to reduced electricity production.

Economy and interruptible sales are assumed to encompass customers with Rider 17; i.e., the power company can, with short notice, reduce sales to these customers by 50%. The highest historical electric furnace demand recorded by customers of Commonwealth Edison with Rider 17 was 442 MW. Therefore, the *maximum* generation reduction would be 221 MW [Ref. 2]*. It is assumed that an hourly *average* reduction of 110 MW is possible if sales to these customers are reduced as much as possible.

"On a day to day basis, neighboring utilities appear able to sell to Edison 500-1000 Megawatts. Some of these companies are contractually bound to sell emergency power for no more than 48 hours for a single set of circumstances" [Ref. 3]. It is assumed that on the average 500 MW can be purchased each hour during a red alert.

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*References are listed in Sec. 13.3.

Table 13.2. Estimated Operating Costs for Power Generation with and Without Load and Fuel Switching with No Reduction in Electricity Generation

Plant Name and Unit #	Loading Order A[a]	Loading Order B[b]	Operating Costs (1976 $) A	Operating Costs (1976 $) B	Operating Costs (1976 $) Difference (A-B)
Chicago SMSA					
Crawford #6	22	31	4,046	0	4,046
Crawford, #7	21	18	76,161	38,856	40,305
Crawford, #8	12	13	102,507	75,103	27,404
Fisk, #18	32	25	22,620	22,620	0
Fisk, #19	13	15	108,713	62,065	46,648
Joliet, #5	30	23	11,432	11,432	0
Joliet, #6	26	16	35,507	48,863	-13,356
Joliet, #7	15	11	108,359	122,496	-14,137
Joliet, #8	14	10	107,339	126,146	-18,807
Ridgeland, #1	18	29	46,344	0	46,344
Ridgeland, #2	16	30	48,242	0	48,242
Ridgeland, #3	19	27	52,873	0	52,873
Ridgeland, #4	20	28	52,020	0	52,020
State Line, #1	33	26	23,098	23,098	0
State Line, #2	31	24	20,448	20,448	0
State Line, #3	23	9	39,950	45,655	-5,705
State Line, #4	24	12	74,604	80,712	-6,108
Waukegan, #5	17	8	35,653	20,958	14,695
Waukegan, #6	9	7	26,004	14,499	11,505
Waukegan, #7	10	6	64,570	45,303	19,267
Waukegan, #8	11	5	68,784	43,556	25,228
Will County, #1	28	20	27,324	27,324	0
Will County, #2	29	21	27,562	27,562	0
Will County, #3	25	14	50,087	60,218	-10,131
Will County, #4	27	19	90,432	90,432	0
Non-SMSA					
Dixon, #4	6	22	13,189	7,668	5,521
Dixon, #5	5	17	16,177	8,878	7,299
Kincaid, #1	4	4	73,137	73,922	-795
Kincaid, #2	3	3	74,098	76,304	-2,206
Powerton, #5	1	1	113,211	114,443	-1,232
Powerton, #6	2	2	102,710	108,922	-6,212
Sabrooke, #3	8	33	20,437	0	20,437
Sabrooke, #4	7	32	28,256	0	28,256
TOTAL COSTS			1,765,877	1,394,475	371,402

[a]With load and fuel switching.

[b]Without load and fuel switching.

Table 13.3. Estimated Cost of Load and Fuel Switching with Simultaneous Reduction in Electricity Generation

Reduction in Electricity Generation[a] (%)	Operating Cost Increase[b] ($)
0	325,362
6	26,333
10	-168,934
20	-633,439
25	-726,881

[a]Based on a typical day output of 241,318 MWh.

[b]Negative numbers imply an operating cost savings.

These data imply that, on the average, about 610 MW of electricity generation can be reduced each hour by restricting sales to economy and interruptible customers and buying outside power. This represents about a six percent reduction in the expected generation of electricity during a typical episode day.* Therefore, during a red alert, it is assumed that a six percent reduction in electricity generation is possible through the curtailment of economy and interruptible sales and the purchasing of power. Thus, the cost of load and fuel switching given in Table 13.3 for a six percent reduction in generation would occur for each day of an episode, as indicated in Table 13.1.

Cost of Buying Power

Based on data provided by Commonwealth Edison Company, it is assumed that, on the average, 500 MW of power can be purchased each hour, as discussed above. "The range of purchased emergency power has been between 13.5 to 70.0 mills per kilowatt hour. The overall average purchase price has been in the range of 33.0 mills per kilowatt hour" [Ref. 1]. Since this cost is

*$(610) \cdot 24/241{,}318 = 0.607 \simeq 0.6$

based on historical information, it is assumed appropriate for 1974. The daily cost of purchasing outside power is: $\$396,000 = 24 \cdot (500 \cdot 10^3) \cdot 33 \cdot 10^{-3}$.

Interruptible/Economy Customer Cost

When interruptible and economy sales are curtailed, the customers affected will incur costs to compensate for the lost electricity. These costs may be expenditures made to supply alternative power or to avoid losses in production. Because the names of the customers affected are confidential, it could not be determined how they would cope with electricity curtailments.

The fact that they are on interruptible contracts implies that normal interruptions in electricity service are relatively inexpensive. However, it is not clear that interruptions in service resulting from an episode are similar to those normally experienced. To estimate the costs to these customers, it is assumed that an alternative source of power is available to them in the form of a company-owned peaking unit. (A peaking unit is assumed because the substitute energy would be electricity). This assumption is based on the fact that many large industrial firms have their own peaking units and it is possible that they also purchase interruptible power. However, no concrete information is available to substantiate this assumption.

The average cost of electricity to the interruptible/economy customers is \$0.0154/kWh [Ref. 2]. The average cost of using peaking units is \$0.0518/kWh [Ref. 1]. The difference of these costs times the amount of electricity produced by the customers' peaking units (110 MW/hour) is the daily cost to the customers of curtailing their electricity service, i.e., $(0.0158 - 0.0154) \cdot (110 \cdot 10^3) \cdot 24 = \$96,096$.

The data obtained from Commonwealth Edison are assumed to be in 1976 dollars. Therefore, this cost in 1974 dollars is: $(147.7/168.6) \cdot 96,096 = \$84,183$/day.* This is the cost used in Table 13.1 as the estimate of the costs of Action 11 to interruptible and economy customers.

*Although prices are regulated, it is assumed the CPI is appropriate for converting 1976 rates to 1974 rates.

This cost estimate is quite tenuous because it is based on little or no information. However, during a red alert, it is likely that the interruptible and economy customers will also have to curtail their activities because of Action 10. If this is true, then the curtailment of electricity sales to them would have little or no cost over and above the cost of Action 10. Therefore, the estimated cost of curtailing sales to interruptible and economy customers most likely only affects the relative efficiency of Action 11 and not the cost estimate of a red alert provided later.

13.2 EMISSION REDUCTION EFFECTS OF ACTION 11

Emission reductions are estimated by multiplying an emission factor in tons/kWh by the kWh generated at each power station unit. The emission factors are based on the fuel used and the efficiency of the unit. Complete details of the procedure and data used are provided in Appendix B.

Table 13.4 shows the estimated emissions for each of the Chicago SMSA power plant units with and without load and fuel switching and no reduction in electricity generation. Table 13.5 summarizes the emission reduction with load and fuel switching and reductions of 0, 6, 10, 20, and 25% in electricity generation, based on 241,318 MWh.

If interruptible and economy customers use their own peakers, emissions will increase by 0.349 tons HC/day and 9.80 tons NO_x/day. The emission factor used for Commonwealth Edison's peaking units were used to make these estimates (see Appendix B). The emission reductions in Table 13.1 assume a six percent reduction in electricity generation and that interruptible and economy customers have their own peakers, i.e.,

$$5.21 - 0.349 = 4.86 \text{ tons HC/day, and}$$

$$173 - 9.8 = 163 \text{ tons } NO_x\text{/day.}$$

13.3 REFERENCES

1. Fancher, J., Commonwealth Edison Company, personal communication (July 12, 1976).

2. Fancher, J., Commonwealth Edison Company, personal communication (July 16, 1976).

3. Fancher, J., Commonwealth Edison Company, personal communication (Sept. 20, 1976).

Table 13.4. Estimated Emissions with and without Load and Fuel Switching and No Reduction in Electricity Generation (tons)

Plant Name and Unit # (Chicago SMSA)	Hydrocarbons (tons)			Nitrogen Oxides (tons)		
	A[a]	B[b]	Difference (A-B)	A[a]	B[b]	Difference (A-B)
Crawford, #6	0.001	0	0.001	0.618	0	0.618
Crawford, #7	0.017	0.195	-0.178	10.42	11.7	-1.28
Crawford, #8	0.027	0.471	-0.444	16.2	28.3	-12.1
Fisk, #18	0.171	0.171	0	10.2	10.2	0
Fisk, #19	0.028	0.432	-0.404	16.6	25.9	-9.30
Joliet, #5	0.063	0.063	0	3.79	3.79	0
Joliet, #6	0.229	0.315	-0.086	13.7	18.9	-5.20
Joliet, #7	0.028	0.823	-0.795	16.4	49.4	-33.0
Joliet, #8	0.028	0.866	-0.838	16.4	51.9	-35.5
Ridgeland, #1	0.011	0	0.011	6.36	0	6.36
Ridgeland, #2	0.011	0	0.011	6.62	0	6.62
Ridgeland, #3	0.012	0	0.012	7.11	0	7.11
Ridgeland, #4	0.012	0	0.012	7.12	0	7.12
State Line, #1	0.180	0.180	0	10.8	10.8	0
State Line, #2	0.133	0.133	0	8.01	8.01	0
State Line, #3	0.244	0.279	-0.035	14.6	16.7	-2.10
State Line, #4	0.452	0.489	-0.037	27.1	29.3	-2.20
Waukegan, #5	0.012	0.217	-0.205	6.99	13.0	-6.01
Waukegan, #6	0.009	0.167	-0.158	5.54	10.0	-4.46
Waukegan, #7	0.021	0.474	-0.453	12.8	28.4	-15.6
Waukegan, #8	0.022	0.424	-0.402	13.0	25.4	-12.4
Will County, #1	0.175	0.175	0	10.5	10.5	0
Will County, #2	0.167	0.167	0	10.0	10.0	0
Will County, #3	0.299	0.359	-0.060	17.9	21.6	-3.70
Will County, #4	0.523	0.523	0	31.4	31.4	0
TOTAL EMISSIONS	2.87	6.92	-4.05	300.5	415	-115

[a]With load and fuel switching.

[b]Without load and fuel switching.

Table 13.5. Emission Reduction Effects of Action 11

Reduction in Electricity Generation[a] (%)	HC Emission Reductions (tons)			NO_x Emission Reductions (tons)		
	Steam Plants	Peakers	Total	Steam Plants	Peakers	Total
0	4.05	0	4.05	115	0	115
6	4.70	0.512	5.21	159	14.4	173
10	5.10	0.839	5.94	187	23.6	211
20	5.97	1.57	7.54	250	44.2	294
25	6.09	1.80	7.89	256	50.6	307

[a]Base is 241,318 MWh.

14 PUBLIC REQUIRED TO AVOID UNNECESSARY USE OF ELECTRICITY -- ACTION 12

During a red alert, the unnecessary use of electricity, such as for decorative or advertising purposes, is prohibited. The impact of the regulation depends on how the public defines "unnecessary electricity" and how many individuals reduce their electricity consumption. Rather than trying to speculate about these variables, the costs and effects of Action 12 are estimated for demand reductions of 0, 2, 5, and 10%. The actual demand reduction will most likely fall in this range. The cost and effect estimates in Table 14.1 are based on a 5% electricity demand reduction.

14.1 COSTS OF ACTION 12

The costs of Action 12 include the cost of notifying the public of the red alert and requesting a reduction in electricity consumption, and the cost associated with reduced electricity consumption.

Notification Cost

Radio and TV announcements are assumed used to notify the public of a red alert and ask them to reduce electricity consumption. The cost of these announcements, derived in Appendix D, is $6,800/day, as shown in Table 14.1.

Table 14.1. Summary of the Costs and Emission Reduction Effects of Prohibiting Unnecessary Use of Electricity[a]

Episode Length (days)	Costs ($\$10^3$)			Emission Reductions (tons)	
	Notification	Net Revenue Loss	Total	HC	NO_x
1	6.80	56.8	63.6	1.13	54.7
2	13.6	114	127	2.26	109
3	20.4	170	191	3.39	164
4	27.2	227	254	4.52	219
5	34.0	284	318	5.65	274

[a] Assuming a 5% electricity demand reduction (i.e., reduction of 12,066 MWh from "typical day" demand of 241,318 MWh).

Net Revenue Loss

The social cost associated with reduced electricity consumption is the foregone satisfaction derived from the consumption of electricity for washing, lighting, entertainment, etc. It is assumed that this cost is equal to the foregone expenditure for electricity.

When electricity demand is reduced some resources (e.g., fuel) used to produce electricity are saved and can be utilized elsewhere in the economy. This saving is a social benefit of reduced electricity consumption. The combined effect of the satisfaction loss and the resource saving is:

$$C = P \cdot \delta - U(\delta) \tag{14.1}$$

where:

$C \equiv$ the social cost of reduced electricity consumption,

$P \equiv$ the price of electricity (\$/MWh),

$\delta \equiv$ MWh of electricity foregone, and

$U(\delta) \equiv$ the savings of resources used to produce electricity, which is a function of the amount of electricity not produced.

Because of the assumptions used to quantify the social cost of reduced electricity, the variable C in Eq. 14.1 is also equal to the net revenue loss to the power company. This is easily seen since $P \cdot \delta$ equals the gross revenues that would have been received from the foregone electricity consumption and $U(\delta)$ is the operating cost of producing the last δ MWh of electricity. Although the net revenue loss interpretation is more easily understood than the social cost interpretation, it should be kept in mind that they are equivalent given the assumptions used in the analysis.

To estimate the net revenue loss, the value of δ is assumed to be between 0 and 10% of the total electricity consumption during a "typical" day of 241,318 MWh.* The 1974 ex post average price paid for electricity, P, was \$24.79/MWh,** and the value of $U(\delta)$ is estimated using the computer simulation model described in Appendix B.

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*See Appendix B for the definition of a typical episode day.

**The 1974 ex post average price of electricity in Illinois was calculated from the total revenues and energy sales of Illinois electric utilities which appear in *Statistical Year Book of the Electric Utility Industry*, Edison Electric Institute, Tables 22S (p.33) and 36S (p.45) (1975).

Table 14.2 summarizes the results of using the above data in Eq. 14.1 for electricity demand reductions of 0, 2, 5, and 10%. Interpolation between these estimates will provide a reasonable estimate of the net revenue loss (social cost) of demand reductions not listed in the table. However, extrapolation beyond 10% may not be appropriate.

14.2 EMISSION REDUCTION EFFECTS OF ACTION 12

The emission reduction effects of Action 12 are estimated using the computer program described in Appendix B. The emission reductions resulting from demand reductions of 0, 2, 5, and 10% are summarized in Table 14.3.

Table 14.2. Net Revenue Losses Due to Action 12

% Demand Reduction[a]	Gross Revenue Loss (A) ($)	Operating Cost Savings (B) ($)	Net Revenue Loss (A-B)[b] ($)
0	0	0	0
2	119,650	96,952	22,699
5	299,119	242,317	56,802
10	598,232	474,869	123,363

[a] 2% reduction = 4,826 MWh foregone on a "typical day," 5% reduction = 12,066 MWh, 10% reduction = 24,132 MWh.

[b] This is the social cost of reduced electricity consumption given the assumptions used in the analysis.

Table 14.3. Emission Reduction Effects of Action 12

% Demand Reduction[a]	HC Emission Reductions (tons)			NO_x Emission Reductions (tons)		
	Steam Plants	Peakers	Total	Steam Plants	Peakers	Total
0	0	0	0	0	0	0
2	0.291	0.170	0.461	17.5	4.80	22.3
5	0.711	0.420	1.13	42.7	12.0	54.7
10	1.27	0.837	2.11	76.4	23.6	100

[a] 2% reduction = 4,826 MWh foregone on a "typical day," 5% reduction = 12,066 MWh, 10% reduction = 24,132 MWh.

14.3 SENSITIVITY ANALYSIS FOR ACTION 12

The cost and effects of Action 12 are highly dependent on the assumed demand reduction δ. For demand reductions between 0 and 10%, the cost of Action 12 for a one-day episode ranges between 0 and \$130,163. However, the efficiency of Action 12, measured as the cost/effectiveness ratios of HC and NO_x reductions, is not very sensitive to the values of δ between 2 and 10%, as shown in Table 14.4.

Table 14.4. Cost/Effectiveness Ratios for Action 12 for a One-Day Episode

% Demand Reduction[a]	Cost/Effectiveness Ratios ($\$10^3$/ton)		
	HC	NO_x	HC and NO_x
2	64.0	1.32	1.30
5	56.3	1.16	1.14
10	61.7	1.30	1.27

[a]2% reduction = 4,826 MWh foregone on a "typical day," 5% reduction = 12,066 MWh, 10% reduction = 24,132 MWh.

15 REQUIRED LIMITS FOR AIR CONDITIONING -- ACTION 13

During a red alert, public, industrial, and commercial space heating is limited to 65°F, and air conditioning to 80°F, except for hospitals and other buildings approved by the IEPA. Since the ozone season occurs during the warmer months of the year only the impact of the setting thermostats at 80°F is evaluated. Because air conditioning is not supposed to be turned off, but rather set at 80°, which is somewhat above the normal setting, one would expect only a partial reduction in the heat sensitive demand to result from Action 13. The cost and emission reduction effects are calculated for air conditioning demand reductions of 0, 5, 10, and 25%. The results in Table 15.1 are based on a 10% reduction in air conditioning electricity demand.

15.1 COSTS OF ACTION 13

The costs of Action 13 include the cost of notifying the public of the red alert and telling them to change their thermostat setting, and the cost associated with reduced electricity consumption for air conditioning.

Notification Cost

Radio and TV announcements are assumed to be used to notify the public of a red alert and tell them to change their thermostat settings. The cost

Table 15.1 Summary of the Costs and Emission Reduction Effects of Requiring Thermostats to Be Set at 80°F[a]

Episode Length (days)	Costs ($\$10^3$)			Emission Reductions (tons)	
	Notification	Net Revenue Loss	Total	HC	NO_x
1	6.80	23.8	30.6	0.475	23.1
2	13.6	47.5	61.1	0.950	46.2
3	20.4	71.3	91.7	1.43	69.3
4	27.2	95.0	122	1.90	92.4
5	34.0	119	153	2.38	116

[a] Assuming a 10% reduction in air conditioning electricity demand (i.e., a reduction of 4,994 MWh from a "typical day" demand of 241,318 MWh).

of these announcements, derived in Appendix D, is \$6,800/day, as shown in Table 15.1.

Net Revenue

The social cost associated with reduced electricity consumption for air conditioning is the foregone satisfaction (comfort) derived from air conditioning. It is assumed that this cost is equal to the foregone expenditure for electricity.

When electricity demand is reduced some resources (e.g., fuel) used to produce electricity are saved and can be utilized elsewhere in the economy. This saving is a benefit of reduced electricity consumption. The combined effect of the satisfaction loss and the resource saving is:

$$C = P \cdot \delta - U(\delta) \tag{15.1}$$

where:

$C \equiv$ the social cost of reduced electricity consumption for air conditioning,

$P \equiv$ the price of electricity (\$/MWh),

$\delta \equiv$ MWh of electricity foregone, and

$U(\delta) \equiv$ the savings of resources used to produce electricity, which is a function of the amount of electricity not produced.

Because of the assumptions used to quantify the social cost of reduced electricity consumption, Eq. 15.1 also can be interpreted as the net revenue loss to the power company. For more details see Sec. 14.1.

The electricity demand originating from air conditioners is not easily isolated from total electricity demand. A Commonwealth Edison load model estimates a 5,300 MWh heat sensitive component based on peak-making weather information [Ref. 1]. The summer's peak-making weather would cause a total peak demand of about 14,000 MWh; therefore, the non-heat-sensitive summer peak demand is 14,000 - 5,300 = 8,700 MWh. As described in Appendix B, an 11,500 MWh peak is being assumed as the expected peak during a "typical" day. The difference between the 11,500 MWh peak and the 8,700 MWh non-heat-sensitive peak demand is 2,800 MWh.

Approximately 15% of Commonwealth Edison's service area is outside the Chicago SMSA and, therefore, must be excluded from the estimation. Thus, the

peak electricity demand from air conditioning within the Chicago SMSA is estimated to be 2,800 • 0.85 = 2,380 MWh, which is about 20.7% of the peak hourly demand of 11,500 MW. Therefore, 5, 10, and 25% reductions in air conditioning electricity demand are equivalent to 1.04, 2.07, and 5.18% reductions in total electricity demand (e.g., 0.05 • 20.7 = 1.04).

To estimate the net revenue loss, the value of δ is assumed to be between 0 and 5.18% of the total electricity consumption during a "typical" day of 241,318 MWh. The 1974 ex post average price paid for electricity, $\bar{P}$, was \$24.79/MWh.* The value of $U(\delta)$ is estimated using the computer simulation model described in Appendix B.

Table 15.2 summarizes the results of using the above data in Eq. 15.1 for air conditioning electricity demand reductions of 0, 5, 10, and 25%. Interpolation between these estimates will provide a reasonable estimate of the net revenue loss (social cost) of demand reductions not listed in the table. However, extrapolation beyond 25% may not be appropriate.

15.2 EMISSION REDUCTION EFFECTS OF ACTION 13

The emission reduction effects of Action 13 are estimated using the computer program described in Appendix B. The emission reductions resulting

Table 15.2. Net Revenue Losses Due to Action 13

% Air Cond. Demand Reduction[a]	Gross Revenue Loss (A) (\$)	Operating Cost Savings (B) (\$)	Net Revenue Loss (A-B)[b] (\$)
0	0	0	0
5	61,910	46,242	15,668
10	123,814	100,060	23,754
25	309,522	250,069	59,453

[a] 5% air conditioning demand reduction (or 1.04% total electricity demand reduction) = 2,497 MWh foregone on a "typical day," 10% (or 2.07%) = 4,994 MWh, and 25% (or 5.18%) = 12,486 MWh.

[b] This is the social cost of reduced electricity consumption given the assumptions used in the analysis.

*Calculated from data in Ref. 2.

from air conditioning demand reductions of 0, 5, 10, and 25% are summarized in Table 15.3.

15.3 SENSITIVITY ANALYSIS FOR ACTION 13

The cost and effects of Action 13 are highly dependent on the assumed demand reduction δ. The impacts of various values of δ can be inferred from the discussion in Sec. 14.3.

15.4 REFERENCES

1. Fancher, James, Commonwealth Edison Company, personal communication (July 16, 1976).

2. *Statistical Year Book of the Electric Utility Industry*, Edison Electric Institute, Tables 22S (p. 33) and 36S (p. 45) (1975).

Table 15.3. Emission Reduction Effects of Action 13

% Air Cond. Demand Reduction[a]	HC Emission Reductions (tons)			NO_x Emission Reductions (tons)		
	Steam Plants	Peakers	Total	Steam Plants	Peakers	Total
0	0	0	0	0	0	0
5	0.099	0.089	0.188	5.96	2.49	8.45
10	0.298	0.177	0.475	17.9	5.15	23.1
25	0.728	0.443	1.17	43.7	12.4	56.1

[a] 5% air conditioning demand reduction (or 1.04% total electricity demand reduction) = 2,497 MWh foregone on a "typical day," 10% (or 2.07%) = 4,994 MWh, and 25% (or 5.18%) = 12,486 MWh.

16 CLOSING GOVERNMENT AGENCIES -- ACTION 14

During a red alert governmental agencies except those needed to administer essential programs are closed. The costs and emission reduction effects of this action are presented in Table 16.1.

16.1 COSTS OF ACTION 14

The costs of closing non-essential governmental agencies include those of (1) notifying employees and individuals who use the agencies' services of the episode action, (2) delaying those services, (3) rescheduling government trucking operations, and (4) using overtime labor to collect solid waste. The assumptions, procedures, and data used to estimate these costs are discussed below.

Notification Cost

Each municipal, county, and state government agency in the affected area is assumed to be informed directly by telephone that a red alert has been called, in order to ensure proper enforcement of the action. This is assumed to be necessary only on the first day of the episode. Assuming each telephone call lasts two minutes, the costs of the telephone calls are estimated as:

$$C = N \cdot (T + W/5040 + \overline{W}/5040) \tag{16.1}$$

Table 16.1. Summary of the Costs and Emission Reduction Effects of Closing Governmental Agencies

Episode Length (days)	Costs ($\$10^3$)					Emission Reductions (tons)	
	Notification	Delay of Services	Rescheduling	Overtime Adjust.	Total	HC	NO_x
1	6.96	5.67	28.9	64.0	106	16.0	7.45
2	13.8	13.0	57.7	128	213	32.0	14.9
3	20.6	21.9	86.6	192	321	47.9	22.4
4	27.4	32.4	115	256	431	63.9	29.8
5	34.2	43.7	144	320	542	79.9	37.3

where:

$C \equiv$ the cost of notifying government agencies,

$N \equiv$ the number of agencies to be contacted,

$T \equiv$ the cost of a telephone call,

$W \equiv$ the monthly wage rate of the person making the telephone call,

$\overline{W} \equiv$ the monthly wage rate of the person receiving the telephone call, and

The constant 5040 is the number of two-minute time periods in a working month of 21 eight-hour days.

To estimate the agency notification cost it is assumed $T = \$0.10$, and $W = \overline{W} = \$1,416$, which is the median income of a low level management employee in metropolitan areas (i.e., Director of Personnel I in Table A.5). The number of agencies to be notified is 242 -- there are 235 municipal, six county and one state governments in the Chicago area. Substituting the values of N, T, W, $\overline{W}$ into Eq. 16.1 results in an estimated cost of notifying government agencies of \$160.

Radio and TV announcements are assumed to be the primary means of notifying employees and "patrons" of government agencies that the agencies will be closed. This cost is \$6,800/day, as derived in Appendix D.

Therefore, the notification costs for an n-day episode are estimated to be:

$$\overline{C} = 6800 \cdot n + 160 \qquad (16.2)$$

The notification costs for various length episodes are provided in Table 16.1.

Delay of Services

To estimate the delay costs for an n-day episode the following equation is used:

$$C' = \sum_{t=1}^{n} D \cdot P_t = D \cdot \sum_{t=1}^{n} P_t \qquad (16.3)$$

where:

$C' \equiv$ the cost of delayed services,

$D \equiv$ the value of the daily services provided by the affected governmental agencies, and

$P_t \equiv$ the delay factor for assumed minimum and maximum delays.

Table 16.2. Assumed Minimum and Maximum Delays and Corresponding Delay Cost Factors

t	Minimum Delay (days)	Maximum Delay (days)	Delay Factor[a] P_t
1	1	8	0.000913
2	2	9	0.001174
3	3	10	0.001435
4	4	11	0.001695
5	5	12	0.001956

[a]A 10% discount rate is assumed; see Table A.7 and discussion in Sec. 2.1.

Table 16.2 summarizes the minimum/maximum delay assumptions used and the resulting delay factors, i.e., P_t. (The procedure used to estimate the delay factors is described in Sec. 2.1.) An explanation of Eq. 16.3 can be found in the discussion of the delay cost of roadway repairs in Sec. 11.1.

It is assumed that the average daily expenditures for various services are the values of the services delayed. The U.S. Census of Governments lists 26 types of local government expenditures [Ref. 2].* Unfortunately, not all of the expenditures in each of the 26 classes neatly fall into activities that are either exempt from or subject to the provisions of Action 14. However, the information needed to disaggregate the expenditure figures further is not readily available. Therefore, it is assumed that either all or none of the expenditures in each of these 26 classes is subject to Action 14.

The 13 expenditure classes that are assumed to be subject to this action are: highways other than capital outlays, public welfare, sanitation other than sewage, parks and recreation, natural resources, housing and urban development other than capital outlays, airports, water transport and terminals, libraries, financial administrations, general control, general public buildings, and other and unallocated.

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*References are listed in Sec. 16.4.

The 13 expenditure classes assumed to be exempt from the action or covered in other actions are: education, highway capital outlays, hospitals, health, police protection, fire protection, sewage, housing and urban development capital outlays, parking facilities, correction, utilities, interest on general debt, and employee-retirement.

Table 16.3 provides the 1971 local government expenditures for the 13 activities assumed subject to the provisions of Action 14. The total annual value of these services is $1.04 billion, which is equivalent to a per capita expenditure of $149.33. To adjust these data to 1974 dollars, the estimated population of the six-county Chicago SMSA in 1974, i.e., 7,141,510 (see Table A.1) is multiplied by $149.33 and then by 147.7/121.3 = 1.22 (the ratio of the two years' Consumer Prices Indices; see Table A.6). This results in an estimated annual expenditure in 1974 by local governments of $1.299 billion, which is equivalent to a daily expenditure of $3,557,656.

Table 16.3. 1971 Local Government Expenditures in the Chicago SMSA

Type of Expenditure	Amount ($\$10^3$)	Per Capita ($)
Highways[a]	116,639	16.71
Public Welfare	159,734	22.89
Sanitation other than Sewage	79,263	11.36
Parks and Recreation	151,884	21.76
Natural Resources	368	0.05
Housing and Urban Renewal[a]	64,308	9.21
Airports	51,119	7.32
Water Transport and Terminals	1,149	0.16
Libraries	30,066	4.31
Financial Administration	38,198	5.47
General Control	90,847	13.02
General Public Buildings	59,070	8.46
Other and Unallocated	199,655	28.61
TOTAL	1,042,300	149.33

Source: *Census of Governments, Local Government in Metropolitan Areas, 1972*, Vol. 5, U.S. Bureau of the Census.

[a]Other than capital outlays.

The delayed local government expenditure per day is \$3.56 million. To estimate delayed expenditures from all levels of government, it is assumed that expenditures are proportional to employment. Table 16.4 provides estimates of 1971 government employment in the six-county Chicago SMSA; from these data it is estimated that 57.3% of the government workers, excluding school district employees, are employed by local governments. Assuming this proportion is constant over time and that the proportion of federal and state expenditures subject to the provisions of Action 14 are the same as the proportion of local expenditures affected, then the value of the daily services provided by the affected governmental agencies, D, is equal to: \$3.56 million/0.573 = \$6.209 million. Substituting this value of D and the values of P_t in Table 16.2 into Eq. 16.3 yields the estimated delay-of-service costs in Table 16.1.

Rescheduling Cost

It is assumed that government trucking operations are affected by Action 14 and that work must be rescheduled after the episode is over. The rescheduling cost of an n-day episode is estimated to be:

$$\tilde{C} + \tilde{N} \cdot \tilde{W} \cdot (\alpha/10,080) \cdot n \tag{16.4}$$

where:

$\tilde{C} \equiv$ the rescheduling costs,

$\tilde{N} \equiv$ the number of vehicles requiring rescheduling,

Table 16.4. Estimated Government Employment in the Chicago SMSA in 1971

Government	Employment
Federal (civilian)	72,919[a]
State	17,835[a]
City and County (non-educational)	121,797
City and County (educational)	116,986[b]
TOTAL	329,537

[a]From Table A.2.

[b]The data in Ref. 4 is for the 1975-76 school year. The figure in the table is adjusted, based on population changes, to reflect 1971 information.

$\tilde{W}$ ≡ the monthly wage rate of the person doing the rescheduling,

α ≡ the average number of minutes required to reschedule each truck, and

The constant 10,080 is the number of minutes in a working month of 21 eight-hour days.

In Chapter 9 it is estimated that 11,419 government trucks operate daily in the Chicago SMSA. If 10% of these are used for emergency purposes, then $\tilde{N} = 11{,}419 \cdot 0.9 = 10{,}277$. Assuming the rescheduling is done by lower level management personnel (i.e., Director of Personnel I in Table A.5), then $\tilde{W} = \$1{,}416$. Setting α equal to 20 results in a rescheduling cost of:

$$\tilde{C} = 28{,}873 \cdot n \qquad (16.5)$$

The rescheduling costs in Table 16.1 are estimated with Eq. 16.5.

Overtime Adjustment Cost

It is assumed that most government activities involving the use of trucks can be made up without overtime (e.g., mail delivery, road repair work, etc.). However, the collection of solid waste is assumed to be made up with overtime labor because of the limited capacity of waste collection trucks and the potential health problems associated with solid waste.

The overtime adjustment cost for an n-day episode is estimated as:

$$\hat{C} = 0.5 \cdot \hat{W} \cdot H \cdot n \qquad (16.6)$$

where:

$\hat{C}$ ≡ the overtime adjustment cost,

$\hat{W}$ ≡ average hourly wage rate of sanitary workers,

H ≡ the number of man-hours lost each day of the episode, and

The constant 0.5 reflects the assumption that the average overtime wage rate is 1.5 times the normal rate.

Refuse in Chicago is collected by approximately 400 work crews [Ref. 1]. Assuming each crew is composed of four persons, then the total work force used to collect refuse is about 1,600 persons. Assuming the total solid waste collection work force in the Chicago SMSA is double this figure, and that eight working hours are lost each day of an episode, then $H = 1{,}600 \cdot 2 \cdot 8 = 25{,}600$ man-hours/day. Setting $\hat{W} = \$5/\text{hr}$ (the average wage rate for production

workers in the Chicago SMSA in 1974) results in an overtime adjustment cost of:

$$\hat{C} = \$64{,}000 \cdot n \tag{16.7}$$

This cost is shown in Table 16.1.

16.2 EMISSION REDUCTION EFFECTS OF ACTION 14

The emission reduction resulting from Action 14 is due to the elimination of employee work trips, truck trips to and from government agencies, and automobile trips to government agencies by the public. It is assumed that schools are not intended to be affected by this action, since Action 15 deals with schools.

The vehicular source effectiveness of Action 14 is estimated as:

$$R_p = A_p + B_p \tag{16.8}$$

where:

- $R_p \equiv$ emission reduction of pollutant p (tons/day);
- $p \equiv$ pollutant: 1 = hydrocarbons, and 2 = nitrogen oxides;
- $A_p \equiv$ emission reduction of pollutant p due to traffic curtailment (tons/day); and
- $B_p \equiv$ emission reduction of pollutant p due to the speed increase of remaining traffic (tons/day).

The variable A_p is calculated as follows:

$$A_p = \sum_{j=1}^{4} (V_j + V_j' \cdot \beta) \cdot E_p(S_j)/907{,}184 + \sum_{j=1}^{4} \sum_{i=3}^{5} V^*_{ij} \cdot E'_{pi}(S_j)/907{,}184 \tag{16.9}$$

where:

- $j \equiv$ traffic segment: 1 = expressway peak, 2 = expressway off-peak, 3 = arterial peak, and 4 = arterial off-peak;
- $V_j \equiv$ passenger auto Vmt during traffic segment j due to government employee work trips (miles/day);
- $V_j' \equiv$ Vmt during traffic segment j by passenger autos making personal business trips (miles/day);
- $\beta \equiv$ fraction of personal business Vmt by passenger autos due to the public's use of nonessential government agencies;
- $E_p(S_j) \equiv$ passenger auto emission rate of pollutant p at average speed S_j before the action (grams/mile);

$i \equiv$ truck classes assumed to be curtailed by Action 14: 3 = light gasoline trucks, 4 = heavy gasoline trucks, and 5 = heavy diesel trucks;

$V^*_{ij} \equiv$ Vmt of trucks of class i during traffic segment j having government buildings or open spaces as their trip origin or destination;

$E'_{pi}(S_j) \equiv$ emission rate of pollutant p by trucks in vehicle class i at average speed S_j before the action (grams/mile); and

The constant 1/907,184 converts grams to tons.

The variable B_p is calculated as:

$$B_p = \sum_{j=1,3} \sum_{i=1}^{9} V_{ij} \cdot [\overline{E}_{pi}(S_j) - \overline{E}_{pi}(S'_j)]/907{,}184 \qquad (16.10)$$

where:

$j \equiv$ traffic segment; j is summed over the two peak traffic segments which experience an average speed increase;

$i \equiv$ vehicle class; i is summed over all nine vehicle classes (see Appendix E);

$\overline{V}_{ij} \equiv$ Vmt of class i vehicles during traffic segment j after the action (miles/day);

$\overline{E}_{pi}(S_j) \equiv$ emission rate of pollutant p for vehicles of class i at average speed S_j before the action (grams/mile);

$\overline{E}_{pi}(S'_j) \equiv$ emission rate of pollutant p for vehicles of class i at average speed S'_j after the action (grams/mile), and

The constant 1/907,184 converts grams to tons.

An implicit assumption in the above formulations is that vehicle trips to nonessential government agencies are not substituted for when such agencies close, i.e., trucks are not rerouted to deliver goods elsewhere, government workers do not make shopping trips, etc.

In 1971 there were approximately 212,551 government employees, excluding those involved in education (see Table 16.4). If essential municipal government services are defined as police and fire protection, and sewage, water supply, and public hospital operations, then 49.0% of SMSA municipal employees perform essential services (see Table 16.5).* For lack of information on the functions performed by other government workers, it is assumed that 49.0% of all government employees perform essential services. Thus,

*Municipal governments do not operate correctional institutions and the number of municipal employees working at municipal parking facilities is assumed to be small. Therefore, the results of Table 16.5 reflect the 13 essential and 13 non-essential government activities defined in Sec. 16.1.

Table 16.5. SMSA Municipal Government 1972 Employment by Function

Function	Employment[a]	%
Police and Fire	25,750	40.0
Sewerage	1,355	2.1
Water Supply	3,738	5.8
Hospitals	715	1.1
All Other	32,810	51.0
TOTAL	64,368	100.0

[a]Based on data from Ref. 2.

212,551 • 0.51 = 108,401 government employees would be affected by the action. Since 108,401 of a total 2,841,659 employees in the SMSA in 1971 (see Table A.2) would be affected by the action, it is assumed that 108,401/2,841,659 = 0.0381 would be the fraction of work trips which would be curtailed.

To calculate the Vmt reduction due to the work trip curtailment, trips must be broken down by mode because many government employees travel to work by mass transit rather than automobile. It is estimated that 69.3%* of government employees in the SMSA, excluding those involved in education, work in the City of Chicago. Assuming all of these employees work in the Chicago Loop, then the fraction of these employees taking mass transit is estimated to be 0.697.** The fraction of total SMSA employees whose passengers auto work trips would be curtailed by the action is equal to: 0.0381 • 0.693 • 0.697 = 0.0184.

Out of a total of 82,842,500 passenger auto Vmt per day, 7.9%, 1.4%, 22.6%, and 4.0% consist of travel having the purpose of work during the expressway peak, expressway off-peak, arterial peak, and arterial off-peak traffic segments, respectively. Thus, work Vmt figures during these four

*Based on the *Suburban Factbook* [Ref. 6], 69.3% of SMSA government employees, excluding those involved in education, worked in the City of Chicago in 1970.

**Of an estimated 825,000 persons entering the Chicago central business district daily for all purposes, approximately 250,000 arrive by passenger automobile [Ref. 8]. Thus, the fraction of persons arriving by mass transit is 1-(250,000/825,000) = 0.697.

traffic segments are equal to 6,544,558, 1,159,795, 18,722,405, and 3,313,700 miles/day, respectively. By multiplying these estimates by 0.0184, estimates of the Vmt curtailed by government workers are obtained (see Table 16.6). Multiplying the Vmt estimates of Table 16.6 by the appropriate low-annual-mileage auto emission factors of Tables E.4 and E.5, the emission reductions due to curtailing the work trips of government employees are estimated to be:

HC reduction = 4.49 tons/day, and

NO_x reduction = 2.51 tons/day.

Passenger auto travel is broken down by trip purpose (see Appendix E): work, work-related, shopping, school, social/recreational, personal business, and other. It is assumed that trips by the public to government agencies are included in the personal business category. Out of a total of 82,842,500 passenger auto Vmt, it is estimated that 2.7% and 7.7% consist of personal business travel during the expressway off-peak and arterial off-peak traffic segments, respectively. Corresponding Vmt figures for these periods are $V_2' =$ 2,236,748 and $V_4' =$ 6,378,873 miles/day. The emissions due to personal business travel are calculated by applying the low-annual-mileage auto emission factors from Tables E.4 and E.5 to these Vmt figures, i.e.,

HC reduction = 52.8•β tons/day, and

NO_x reduction = 40.5•β tons/day

Depending on the fraction of personal business travel which consists of trips to nonessential government agencies, the potential emission reduction from closing the agencies may be significant. For lack of information, it is

Table 16.6. Vmt Curtailed of Nonessential Government Workers

Traffic Segment	Daily Vmt Curtailed (V_j in Eq. 16.9)
Expressway Peak	120,420
Expressway Off-Peak	21,340
Arterial Peak	344,492
Arterial Off-Peak	60,972
TOTAL	547,224

assumed that 5% of personal business auto Vmt consists of trips to and from nonessential government agencies, i.e., $\beta = 0.05$.

The Vmt estimates for trucks making trips to and from government buildings and open spaces are based on data obtained from CATS [Ref. 7]. The data from CATS include the daily number of internal eight-county truck trips made to public buildings and open spaces; the fraction of these trips made by CATS-defined light, medium, and heavy trucks; and the average length of such trips for each type of truck.

The Vmt by trucks making trips to government buildings and open spaces are estimated by multiplying [the number of trips] by [the fraction of trips made by each truck type] by [the average trip length for each truck type]. The resulting Vmt figures are 159,265 miles/day for light trucks, 7,178 miles/day for medium trucks, and 33,029 miles/day for heavy trucks.

The Vmt by trucks whose trips originate at government buildings or open spaces are calculated by multiplying [the number of trips originating at public buildings or open spaces and having a particular destination (commercial, manufacturing, etc.)] by [the fraction of total trips arriving at that destination for each type of truck] by [the average length of such trips]. The sum of Vmt for all destination categories excluding public buildings and open spaces is then the total Vmt of trucks originating at government buildings and agencies: 104,330 miles/day for light trucks, 15,790 miles/day for medium trucks, and 36,300 miles/day for heavy trucks.

Thus, Vmt for the eight-county CATS study area by trucks making internal trips having government buildings or open spaces as origins or destinations are 263,595 miles/day for light trucks, 22,968 miles/day for medium trucks, and 69,329 miles/day for heavy trucks.

In addition, a total of 1,570 external truck trips are made daily to and from government buildings and open spaces. Multiplying [the number of trips] by [the fraction of total external truck trips by each truck type] by [the average external trip length for each truck type], the external Vmt by trucks making trips to and from government buildings and open spaces are 9,272 miles/day for light trucks, 4,573 miles/day for medium trucks, and 44,268 miles/day for heavy trucks. Of total eight-county internal light truck Vmt, 89.5% occurs in the SMSA; 96.4% of medium truck Vmt and 90.4% of heavy truck Vmt occur in

the SMSA.* Applying these proportions to the above Vmt estimates, the SMSA values of 244,216 miles/day, 26,550 miles/day, and 102,692 miles/day for light, medium, and heavy trucks, respectively, are estimated.

The procedure described in Sec. E.4 is employed to convert the CATS truck categories to the three truck classes used in this study. The resulting Vmt estimates for trucks making trips to and from government buildings and open spaces are 171,440 miles/day for light gasoline-powered trucks, 133,279 miles/day for heavy gasoline-powered trucks, and 68,740 miles/day for heavy diesel trucks.

It is assumed that the percentage of the truck Vmt curtailed is equal to the percentage of government employees affected by the action (51.0%). The daily truck Vmt actually curtailed would then amount to 171,440 • 0.51 = 87,434 for light gas trucks; 133,279 • 0.51 = 67,972 for heavy gas trucks; and 68,740 • 0.51 = 35,057 for heavy diesel trucks. It is assumed that these truck Vmt estimates are proportioned among the four traffic segments the same as general truck traffic, as discussed in Appendix E: 0.075/0.184/0.216/0.525 for the expressway peak, expressway off-peak, arterial peak, and arterial off-peak traffic segments, respectively. The resulting Vmt estimates by traffic segment (V^*_{ij} in Eq. 16.9) are shown in Table 16.7. Applying the emission factors of Tables E.4 and E.5 to the Vmt data of Table 16.7 according to Eq. 16.9, the truck emission reductions are estimated:

HC reduction = 3.14 tons/day, and
NO_x reduction = 2.22 tons/day.

The emission reductions due to the curtailment of traffic are:

$A_1 = 4.49 + 52.8 \cdot 0.05 + 3.14 = 10.3$ tons HC/day, and
$A_2 = 2.51 + 40.5 \cdot 0.05 + 2.22 = 6.76$ tons NO_x/day.

From the Vmt data of Table 16.8, assuming 5% of personal business Vmt is for trips to nonessential government agencies, it is estimated that the average speed of arterial peak traffic will increase from 11.9 mph to 12.4 mph; expressway peak traffic will experience a speed increase from 43.7 mph to 44.0 mph. Emission factors for all vehicle classes were calculated at these new average speeds and used to estimate the speed increase effect from

*See Appendix E.

Table 16.7. Truck Vmt Curtailed by Action 14

	Vmt Curtailed (V^*_{ij} in Eq. 16.9)			
Truck Class	Expressway Peak	Expressway Off-Peak	Arterial Peak	Arterial Off-Peak
Light Gasoline	6,558	16,088	18,886	45,903
Heavy Gasoline	5,098	12,507	14,682	35,685
Heavy Diesel	2,629	6,451	7,572	18,405
TOTAL	14,285	35,046	41,140	99,993

Eq. 16.10. The emission reductions resulting from the speed increases are:

HC reduction = 5.07 tons/day, and

NO_x reduction = 0.690 tons/day.

The vehicular source effectiveness of Action 14 is then:

R_1 = 10.3 + 5.07 = 15.4 tons HC/day, and

R_2 = 6.76 + 0.690 = 7.45 tons NO_x/day.

The total HC emission reduction is the sum of R_1 and the evaporative emission reduction due to reduced average sales of gasoline. The evaporative emission reduction is estimated in Appendix G to be 0.631 tons HC/day. Therefore:

Total HC reduction = 15.4 + 0.631 = 16.0 tons/day.

Table 16.8. Speed Increase Data

Traffic Segment	Vmt before Action (miles/day)	Vmt after Action (miles/day)	Vmt per Hour after Action	Avg. Speed after Action[a] (mph)
Expressway Peak	7,451,000	7,316,295	1,463,259	44.0
Arterial Peak	21,393,000	21,007,368	4,201,474	12.4

[a]Based on peak speed adjustment Eqs. F.1 and F.2 in Appendix F.

16.3 SENSITIVITY ANALYSIS FOR ACTION 14

The rescheduling cost of Action 14 is sensitive to the assumed average time required to reschedule government truck operations, i.e., α. Since the rescheduling cost is proportional to α a change in α of x% will result in a change in the estimated rescheduling cost of x%. The rescheduling cost is about 28% of the total cost estimate, therefore an x% change in the rescheduling cost will result in total cost change of $(0.28 \cdot x)\%$.

We set α = 20 min/truck. In all likelihood this is a high estimate. If α is closer to 2 minutes then the total cost estimate is only overestimated by about 25%, which is well within the accuracy of the analysis.

16.4 REFERENCES

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3. *Census of Governments, Public Employment, Number 1, Employment of Major Local Governments, 1972,* Table 2, U.S. Bureau of the Census.

4. *Fall Public Enrollment and Teacher Statistics, Illinois Public Schools, 1975-1976 School Year,* Census Series A #354, State Board of Education, Illinois Office of Education, Springfield, Illinois.

5. *Illinois State and Regional Economic Data Book,* Dept. of Business and Economic Development, State of Illinois (1973).

6. *Suburban Factbook, 1973,* Northeastern Illinois Planning Commission.

7. Warnke, J., and D.A. Zavattero, *Motor Truck Freight in the Chicago Region,* Chicago Area Transportation Study (to be published).

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17 SCHOOL CLOSINGS -- ACTION 15

During a red alert all schools close immediately -- except elementary schools (Grades 1-8), which close at the end of the normal school day -- and do not reopen until the alert is terminated. The cost and emission reduction effects of Action 15 are summarized in Table 17.1.

17.1 COSTS OF ACTION 15

The costs of Action 15 are those of (1) notifying school staff, students, and parents of the school closing, and (2) child care for elementary school children with working mothers.* The data, assumptions, and methods used to estimate these costs are presented below.

Notification Cost

School closings for snow storms and other unplanned and infrequent events occur periodically and the standard procedure for notifying students, parents, teachers, and other school personnel are the "no school" announcements made on radio and TV. It is assumed that this will be the procedure used for air pollution episodes. The cost of radio and TV announcements, estimated in Appendix D, is $6,800/day.

Table 17.1. Summary of the Costs and Emission Reduction Effects of Closing Schools

Episode Length (days)	Costs ($\$10^3$)			Emission Reductions (tons)	
	Notification	Child Care	Total	HC	NO_x
1	4.69	540	545	15.2	5.66
2	9.24	1080	1090	30.4	11.3
3	13.8	1620	1630	45.6	17.0
4	18.4	2160	2180	60.8	22.6
5	22.9	2700	2720	75.9	28.3

*The estimates of child care costs are based on data on the number of working mothers of elementary school children in the Chicago SMSA; child care costs for single fathers of such children are not considered, since they are likely to be quite small. It is also assumed that nearly all husbands of married mothers work and are unavailable for child care.

The superintendent of each school district in the affected area is assumed to be notified by telephone that a red alert has been called. Assuming each telephone call last two minutes, the telephone notification cost is:

$$\tilde{C} = N \cdot (T + W/5040 + \overline{W}/5040) \tag{17.1}$$

where:

$\tilde{C}$ ≡ the cost of notifying school superintendents,

N ≡ the number of school districts called,

T ≡ the cost of a telephone call,

W ≡ the monthly wage of the person making the telephone call,

$\overline{W}$ ≡ the monthly wage of the person receiving the telephone call, and

The constant 5040 is the number of two-minute time periods in a working month of 21 eight-hour days.

To estimate the school superintendent notification costs it is assumed that $T = \$0.10$ and $W = \overline{W} = \$1,416$, which is the median income of a low-level management employee in metropolitan areas (i.e., Director of Personnel I in Table A.5). The number of school districts in the Chicago SMSA, N, is 302 [Ref. 4].* Substituting the values of N, T, W, $\overline{W}$ into Eq. 17.1 results in an estimated cost of notifying school superintendents of $\tilde{C} = \$199.90$.

To account for the fact that school is not in session for the entire year the following assumptions are made: (1) the regular school session begins in the middle of September and ends in the middle of June, (2) the maximum summer session is six weeks long (this was the maximum length of a summer session in DuPage County in 1974 [Ref. 6], (3) the ozone season lasts from April 1 through September 30 [Ref. 5], (4) the probability of closing school during a given month is proportional to the daily maximum one-hour average ozone level recorded in Illinois during the 1975 ozone season, and (5) the average number of work days each month is 21.

Tables 17.2 and 17.3 are based on the above assumptions. The P_{jt} values in Table 17.2 are the estimated probabilities of school being in regular session (j=1), summer session (j=2), or recess (j=3) in month t. The $\overline{P}_t$ values in Table 17.3 are the probabilities of a school closing because of an episode each month, given that a red alert will occur. Assuming these events are independent, $\overline{P}_t \cdot P_{jt}$ is the probability of school being in session j and a red

*References are listed in Sec. 17.4.

Table 17.2. School Days during Ozone Season

Month, t	Regular Session No. of Days of School	P_{1t}	Summer Session No. of Days of School	P_{2t}	Recess No. of Days of School	P_{3t}
April, 1	21.0	1.0	0	0	0	0
May, 2	21.0	1.0	0	0	0	0
June, 3	10.5	0.5	10.5	0.5	0	0
July, 4	0	0	19.5	0.93	1.5	0.07
Aug., 5	0	0	0	0	21.0	1.0
Sept., 6	10.5	0.5	0	0	10.5	0.5

Table 17.3. Daily Maximum One-Hour Average Ozone Concentrations

Month, t	Max. Ozone[a] (ppm)	$\overline{P}_t$
April, 1	0.106	0.11
May, 2	0.116	0.12
June, 3	0.156	0.17
July, 4	0.207	0.22
Aug., 5	0.233	0.25
Sept., 6	0.121	0.13
		1.00

[a]From Ref. 5.

alert being called in month t. Let $C_j(n)$ be the notification cost for an n-day red alert when school is in session j; then the expected notification cost would be:

$$C = \sum_{t=1}^{6} \sum_{j=1}^{3} \overline{P}_t \cdot P_{jt} \cdot C_j(n) \tag{17.2}$$

Substituting the values of $\overline{P}_t$ and P_{jt} from Tables 17.2 and 17.3 and setting $C_j(n) = 6{,}800 \cdot n + 200$,* for j = 1,2 and $C_j(n) = 0$ for j = 3 yields the expected notification costs indicated in Table 17.1.

*This formulation assumes the telephone calls to the superintendents only occur on the first day of the episode.

Child Care Cost

A special problem associated with school closings is the care of young school-age children of working mothers. Data from the U.S. Department of Labor [Ref. 2], reproduced in Table 17.4, indicate that about 45% of all mothers with children under age 18 living at home are in the labor lorce, and that the average family has 2.14 children under age 18. Assuming these statistics are applicable to the Chicago area, then the number of families with working mothers and children under age 18 in the Chicago area is equal to:

$$F = (P_{18}/2.14) \cdot 0.45 \tag{17.3}$$

where P_{18} is the number of persons less than 18 years old in the Chicago SMSA in 1974. In 1970, 34.6% of the 6,977,611* persons who lived in the six-county Chicago area was composed of individuals under age 18 [Ref. 3]. The population in the Chicago SMSA in 1974 is estimated to be 7,141,510.* Assuming that the proportion of people under 18 remained constant between 1970 and 1974, P_{18} = 2,470,962. Therefore, based on Eq. 17.3, the estimated number of families in the Chicago SMSA with children under age 18 and working mothers is 519,595.

Table 17.4. Mothers with Children under Age 18 in the Labor Force in 1974 in the United States

Type of Family	Thousands of Families	Avg. No. of Children
Husband-Wife Families	25,275	2.14
Mother in Labor Force	10,907	2.03
Mother not in Labor Force	14,368	2.23
Mother Only	4,080	2.12
Mother in Labor Force	2,438	1.89
Mother not in Labor Force	1,642	2.46
All Families	29,355	2.14
Mother in Labor Force	13,345 (45%)	2.00
Mother not in Labor Force	16,010 (55%)	2.25

*See Table A.1.

To estimate how many of these families will require extra child care services if schools are closed, it is assumed that only families with a child or children in Grades 1-8 will need extra child care. This assumption reflects the fact that child care for preschoolers is unaffected by school closings and high school students do not need supervision.

It is known that approximately 25% of all working mothers with children under 18 have at least one preschooler [Ref. 2]. If it is assumed that half of these mothers also have at least one other child in school, then an estimated 519,595 · 0.25 · 0.5 = 64,949 families with working mothers have only preschoolers. Therefore, 519,595 - 64,949 = 454,646 families with working mothers have at least one child in school. If it is also assumed that 50% of these families have at least one child in elementary school, then an estimated $F_s = 0.5 \cdot 454{,}646 = 227{,}323$ families will require extra child care services if schools are closed.

To estimate the number of families requiring extra child care services, two assumptions are made for which no information is available. These are the assumptions on the percentage of families with only preschoolers and/or high schoolers. A general equation of the number of families requiring child care services as a function of these assumptions is:

$$F_s = 2{,}470{,}962 \cdot \rho_1 \cdot [0.2103 - 0.0526 \cdot (1 - \rho_2)] \tag{17.4}$$

where:

$F_s \equiv$ the number of families requiring extra child care services if schools are closed,

$\rho_1 \equiv$ the fraction of families with working mothers and school children that has at least one child in elementary school $(0 \leq \rho_1 \leq 1)$,

$\rho_2 \equiv$ the fraction of families with working mothers with at least one preschooler that also has at least one school-age child $(0 \leq \rho_2 \leq 1)$, and

The constant 2,470,962 is the number of persons under 18 in the Chicago SMSA in 1974 (i.e., P_{18}).

For this analysis it is assumed that $F_s = 227{,}323$, i.e., $\rho_1 = \rho_2 = 0.5$.*

Assigning a value of \$1/hr for child care per family with a working mother and at least one elementary school child yields an hourly child care

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*Actual substitution of $\rho_1 = \rho_2 = 0.5$ in Eq. 17.4 yields $F_s = 227{,}329$; the difference is a round-off error.

cost of \$227,323 when school is in regular session. During the summer session approximately 18% of all students are in school [Refs. 1, 6]. Therefore, the child care costs during the summer session are assumed to be 18% of the regular session costs or \$40,918/hr.

Using Eq. 17.2 and setting $C_j(n)$ equal to the child care cost during session j, hourly child care costs are: $\hat{C} = 0.38 \cdot \$227,323 + 0.29 \cdot \$40,918 =$ \$98,249/hr. If the work day is defined to be between 8 a.m. and 5 p.m. and the school day is defined to be between 8 a.m. and 3:30 p.m., then 5.5 hours of extra child care will be required for each family with a working mother and an elementary school child if schools are closed. This implies a daily cost of child care of $5.5 \cdot \$98,249 = \$540,370$. For an episode of n days, the total child care costs would be:

$$\overline{C} = \$540,370 \cdot n \tag{17.5}$$

This cost is reflected in the estimates provided in Table 17.1.

Rescheduling Cost

Many school districts routinely include make-up days in their schedules, to avoid rescheduling if school is closed unexpectedly. Similar provisions could be made for the summer session when the summer schedules are determined. Virtually no additional time or effort would be required, therefore, the costs would be insignificant.

Furthermore, the delay of educational services that may occur because of school closings does not involve real costs because education is an investment toward future earnings or well-being. Since future earnings or well-being are unlikely to be affected, the value of the educational services is unchanged. No educational services are lost, which would be a cost, because it is assumed that all lost days are made up at the end of a school session.

School bus drivers are informed of school closures through the radio/TV announcements. Furthermore, school bus schedules should be the same as the school schedule. Thus, make-up days are included and no rescheduling costs occur for make-up days. No losses occur since no bus service is lost.

17.2 EMISSION REDUCTION EFFECTS OF ACTION 15

Emission reductions occur due to the elimination of school bus travel and traffic from autos transporting teachers and children to school. The effectiveness of the action is estimated with the following equation:

$$R_p = A_p \cdot f + \overline{A}_p \cdot u + G_p \qquad (17.6)$$

where:

- R_p ≡ emission reduction of pollutant p (tons/day);
- p ≡ pollutant: 1 = hydrocarbons, and 2 = nitrogen oxides;
- A_p ≡ emission reduction of pollutant p when schools are in full session (tons/day);
- f ≡ probability of an ozone red alert occurring when schools are in full session;
- $\overline{A}_p$ ≡ emission reduction of pollutant p when schools are in summer session (tons/day);
- u ≡ probability of an ozone red alert occurring when schools are in summer session; and
- G_p ≡ evaporative emission reductions due to reduced gasoline sales.

The variable A_p is calculated as follows, where the first term represents the emission reduction due to the traffic curtailment and the second term represents the emission reduction due to the speed increase of the remaining traffic.

$$A_p = \sum_{j=1}^{4} [V_j \cdot E_p(S_j) + (V'_j + V^*_j) \cdot E'_p(S_j)]/907{,}184$$
$$+ \sum_{j=1,3} \sum_{i=1}^{9} [V^{\circ}_{ij} - V_j - V'_j - V^*_j] \cdot [E^{\circ}_{pi}(S_j) - E^{\circ}_{pi}(S^*_j)]/907{,}184 \qquad (17.7)$$

where:

- j ≡ traffic segment: 1 = expressway peak, 2 = expressway off-peak, 3 = arterial peak, and 4 = arterial off-peak;
- V_j ≡ full session school bus Vmt during traffic segment j (miles/day);
- $E_p(S_j)$ ≡ school bus emission factor for pollutant p at average speed S_j before the action (grams/mile);
- V'_j ≡ full session Vmt of autos during traffic segment j making trips with the purpose of "school" (miles/day);
- V^*_j ≡ full session Vmt of autos used during traffic segment j to transport school teachers to and from work (miles/day);
- $E'_p(S_j)$ ≡ low-annual-mileage auto emission rate of pollutant p at average speed S_j before the action (grams/mile);
- i ≡ vehicle class (see Appendix E);

V^{o}_{ij} ≡ full session Vmt of vehicles of class i during traffic segment j before the action (miles/day);

$E^{o}_{pi}(S_j)$ ≡ emission rate of pollutant p by vehicles of class i at average speed S_j before the action (grams/mile);

$E^{o}_{pi}(S^*_j)$ ≡ emission rate of pollutant p by vehicles of class i at average speed S^*_j after the action; and

The constant 1/907,184 converts grams to tons.

The variable $\overline{A}_p$ is calculated as follows:

$$\overline{A}_p = \sum_{j=1}^{4} [\overline{V}_j \cdot E_p(\overline{S}_j) + (\overline{V}'_j + \overline{V}^*_j) \cdot E'_p(\overline{S}_j)]/907{,}184$$

$$+ \sum_{j=1,3} \sum_{i=1}^{9} [\overline{V}^{o}_{ij} - \overline{V}_j - \overline{V}'_j - \overline{V}^*_j] \cdot [E^{o}_{pi}(\overline{S}_j) - E^{o}_{pi}(\overline{S}^*_j)]/907{,}184 \qquad (17.8)$$

where each variable with a bar above it is defined as it was, without the bar, for Eq. 17.7, except that it applies when summer school is in session; the constant and i and j are defined identically.

Implicit in Eqs. 17.6 - 17.8 are the following assumptions: (1) public transportation would not be significantly affected due to the elimination of school trips, and (2) substitute trips would not be made for recreational or other purposes if students and teachers were not required to be at school.

As discussed in Appendix E, school bus Vmt when school is in full session is estimated at 10,591 miles/day during each of the expressway traffic segments (V_1 and V_2 in Eq. 17.7) and 30,145 miles/day during each of the arterial traffic segments (V_3 and V_4 in Eq. 17.7). Emission factors for school buses [$E_p(S_j)$ in Eq. 17.7] are given in Tables E.4 and E.5.

Estimates of passenger auto travel having the purpose of "school" when school is in full session are based on data appearing in Appendix E. Out of the total passenger auto Vmt of 82,842,500 miles/day, 1.2% consists of travel having the purpose of "school," with 0.2% during each of the expressway traffic segments and 0.4% during each of the arterial traffic segments. Thus, school Vmt (V'_j in Eq. 17.7) amounts to 165,685 miles/day in each of the expressway traffic segments and 331,370 miles/day in each of the arterial traffic segments.

The emission reductions from school teachers curtailing their work trips are calculated as follows. In Appendix E, it is estimated that out of a total of 82,842,500 miles/day traveled by passenger autos, 7.9%, 1.4%, 22.6%,

and 4.0% consist of travel having work as its purpose during the expressway peak, expressway off-peak, arterial peak, and arterial off-peak traffic segments, respectively. Thus, work Vmt during the four traffic segments amounts to 6,544,558 miles/day, 1,159,795 miles/day, 18,722,405 miles/day, and 3,313,700 miles/day. In 1971, approximately 116,986 workers in the SMSA were on school staffs. Since there were 2,841,659 total employees in the SMSA in 1971 (see Table A.2) about 4.12% of these are school employees. Assuming the same fraction of work trip Vmt is made by school employees, then auto Vmt by school employees driving to and from work (V_j^* in Eq. 17.7), by traffic segment, are 269,636 miles/day for j=1, 47,784 miles/day for j=2, 771,363 miles/day for j=3, and 136,524 miles/day for j=4. By applying the low-annual-mileage auto emission factors [$E'_p(S_j)$ in Eq. 17.7] of Tables E.4 and E.5 to the Vmt reduction estimates as in Eq. 17.7, and summing with the school bus emissions, the following emission reductions from traffic curtailment are obtained: HC reduction = 19.8 tons/day, and NO_x reduction = 11.2 tons/day.

The Vmt reduction during the peak periods results in an increase in the average arterial peak speed from 11.9 mph to 13.4 mph and an increase in the average expressway peak speed from 43.7 mph to 44.6 mph (see Table 17.5). Emission factors for all classes of vehicles are calculated at these new average speeds [$E^\circ_{pi}(S_j^*)$ in Eq. 17.7] and used to estimate the speed increase effect from Eq. 17.7. The resulting emission reductions from the speed increases are 14.4 tons HC/day and 1.93 tons NO_x/day.

The total vehicular source emission reductions when school is in full session are estimated at:

$$A_1 = 19.8 + 14.4 = 34.2 \text{ tons HC/day, and}$$
$$A_2 = 11.2 + 1.93 = 13.1 \text{ tons } NO_x\text{/day.}$$

Table 17.5. Speed Increase Data, Full Session

Traffic Segment	Vmt before Action (miles/day)	Vmt after Action (miles/day)	Vmt per Hour after Action	Avg. Speed after Action[a] (mph)
Expressway Peak	7,451,000	7,005,088	1,401,018	44.6
Arterial Peak	21,393,000	20,260,122	4,052,024	13.4

[a]Based on peak speed adjustment equations in Appendix F.

It is assumed that school Vmt during the summer session is equal to 18% of the full session Vmt, the same proportional decline as enrollment [Refs. 1, 6]. Reductions of Vmt during the summer session are shown in Table 17.6.

Since school traffic is reduced during summer session, the average vehicle speeds during peak periods would be greater than when school is in full session. The average traffic speeds during summer session, estimated from the peak speed adjustment equations, are 44.4 mph for the expressway peak period, and 13.2 mph for the arterial peak period ($\overline{S}_j$ in Eq. 17.8). The emission reductions from eliminating school traffic during the summer session are calculated by applying the emission factors at speeds $\overline{S}_j$ to the Vmt data of Table 17.6, as shown in Eq. 17.8: HC reduction = 3.44 tons HC/day, and NO_x reduction = 2.00 tons NO_x/day.

The Vmt reduction during the peak periods results in an increase in the average arterial peak speed from 13.2 mph to 13.4 mph and an increase in the average expressway peak speed from 44.4 mph to 44.6 mph (see Table 17.7). Emission factors for all classes of vehicles are calculated at these new average speeds ($E^{\circ}_{pi}(\overline{S}^*_j)$ in Eq. 17.8) and used to estimate the speed increase effect from Eq. 17.8. The resulting emission reductions from the speed increases are 2.58 tons HC/day and 0.340 tons NO_x/day.

The total vehicular source emission reductions when school is in summer session are estimated at:

$\overline{A}_1$ = 3.44 + 2.58 = 6.02 tons HC/day, and
$\overline{A}_2$ = 2.00 + 0.340 = 2.34 tons NO_x/day

Table 17.6. Summer Session Vmt Reduction

	Vmt Reductions (miles/day)			
Vehicle Class and Vmt Variables in Eq. 17.8	Expressway Peak	Expressway Off-Peak	Arterial Peak	Arterial Off-Peak
School Bus ($\overline{V}_j$)	1,906	1,906	5,426	5,426
Passenger Auto School Trips ($\overline{V}'_j$)	29,823	29,823	59,647	59,647
Passenger Auto Teacher Work Trips ($\overline{V}^*_j$)	48,534	8,601	138,845	24,574
TOTAL	80,263	40,330	203,918	89,647

Table 17.7. Speed Increase Data, Summer Session

Traffic Segment	Vmt before Action (miles/day)	Vmt after Action (miles/day)	Vmt per Hour after Action	Avg. Speed after Action[a] (mph)
Expressway Peak	7,085,351	7,005,088	1,401,018	44.6
Arterial Peak	20,464,040	20,260,122	4,052,024	13.4

[a]Based on peak speed adjustment equations in Appendix F.

The evaporative hydrocarbon emission reduction, G_1, is estimated in Appendix G to be 1.12 tons HC/day during the full session and 0.202 tons HC/day during the summer session. The value of G_2 is equal to zero.

The probability of an ozone alert being called when school is in full session is estimated from data in Tables 17.2 and 17.3, i.e.,

$$f = \sum_{t=1}^{6} P_{1t} \cdot \overline{P}_t = 0.38 \qquad \text{and} \qquad u = \sum_{t=1}^{6} P_{2t} \cdot \overline{P}_t = 0.29$$

From Eq. 17.6 the effectiveness of the action is estimated as:

$R_1 = (34.2 + 1.12) \cdot 0.38 + (6.02 + 0.202) \cdot 0.29 = 15.2$ tons HC/day, and
$R_2 = 13.1 \cdot 0.38 + 2.34 \cdot 0.29 = 5.66$ tons NO_x/day.

17.3 SENSITIVITY ANALYSIS FOR ACTION 15

The child care cost is a function of the assumed values of ρ_1 and ρ_2 in Eq. 17.4. The maximum cost estimate occurs when $\rho_1 = \rho_2 = 1$. This is equivalent to assuming that all families with working mothers and children under 18 have at least one child in elementary school. In this case the daily child care cost would be \$519,643. If no working mothers have elementary school children, then the child care cost would be zero. A mid-range estimate is assumed in the analysis.

Other important variables in the analysis of Action 15 are the estimated values of $\overline{P}_t$, i.e., the likelihoods of an episode being called in month t given that an episode will be called. For example, if it is assumed that in April, May, and September the likelihood of schools being closed due to an ozone episode is zero, then the estimated probabilities of an episode occuring during

the regular, summer, and recess sessions would be 13.5%, 45.1% and 41.4%, respectively. With this assumption the expected daily child care cost would be: $(0.135 \cdot \$227{,}323 + 0.451 \cdot \$40{,}918) \cdot 5.5 = \$270{,}284$.

However, the emission reduction effects are also changed when the values of $\overline{P}_t$ are altered, i.e., $R_1 = 35.3 \cdot 0.135 + 6.22 \cdot 0.451 = 7.57$ tons HC, and $R_2 = 13.1 \cdot 0.135 + 2.34 \cdot 0.451 = 2.82$ tons NO_x.

Therefore, the cost/effectiveness ratios (exclusive of the notification cost) are hardly affected by the values of $\overline{P}_t$. For example, for HC the cost/effectiveness ratio with the values of $\overline{P}_t$ in Table 17.3 is $\$540.370 \cdot 10^6/15.19 = \$35.6 \cdot 10^6$/ton compared to $\$270.284 \cdot 10^6/7.57 = \$35.7 \cdot 10^6$/ton for $\overline{P}_t$ equal to 0, 0, 0.27, 0.34, 0.39, and 0 for t = 1 to 6, respectively.

17.4 REFERENCES

1. City of Chicago School Board, personal communications (1976).

2. *Children of Working Mothers, March 1974,* Special Labor Force Report #174, U.S. Dept. of Labor, Bureau of Labor Statistics (1975).

3. *County and City Data Book 1972,* U.S. Dept. of Commerce, Bureau of the Census (1974).

4. *Illinois Public School Districts 1975-1976 School Year,* Circular Series 11, No. 346, Illinois Office of Education, Springfield, Ill. (1975).

5. Schoen, T.A., *Testimony on the Proposed Amendments to the Illinois Air Pollution Episode Regulations,* Episode and Emergency Response Section, Illinois Environmental Protection Agency (Feb. 24, 1976).

6. *Survey of Summer School Programs - DuPage County School Districts,* typed data sheets obtained from Naperville School District (1974).

18 LOADING OF VOLATILE ORGANIC MATERIAL PROHIBITED -- ACTION 16

During a red alert the loading of more than 250 gal. of volatile organic material into any stationary tank, railroad tank car, tank truck, or tank trailer is prohibited except where an integral part of an industrial operation allowed during a red alert. Volatile organic material is defined in the episode regulation as any organic material with a vapor pressure of 2.5 lbs/in^2 absolute (psia) or greater at 70°F. However, for this analysis only the handling of gasoline (including diesel fuels), except for its sale at the pump, is considered. More information is required before the analysis can be extended to other organic materials. However, the error introduced by limiting the analysis to gasoline handling may be small since staff from the Illinois EPA indicate that this action is primarily designed to restrict the handling of gasoline during an episode [Ref. 3].* The cost and emission reduction effects of this action are summarized in Table 18.1.

18.1 COSTS OF ACTION 16

The costs of Action 16 estimated are those of notification, rescheduling, and overtime labor. Very little information about gasoline handling operations was available to the research team, making the evaluation of this action quite difficult. Of particular concern is the possible cost of tying up transportation equipment (trucks, railroad tank cars, etc.) that

Table 18.1. Summary of the Costs and Emission Reduction Effects of Prohibiting the Loading of Volatile Organic Material

Episode Length (days)	Costs ($\$10^3$) Notification	Rescheduling	Overtime	Total	HC Emission Reduction (tons) Loading, Unloading	Delivery Vehicles	Total	NO_x Emission Reduction (tons)[a]
1	6.80	3.05	43.4	53.3	36.0	0.106	36.1	0.758
2	13.6	6.10	86.8	107	72.0	0.212	72.2	1.52
3	20.4	9.14	130	160	108	0.318	109	2.27
4	27.2	12.2	174	213	144	0.424	145	3.03
5	34.0	15.2	217	266	180	0.530	181	3.79

[a] NO_x emission reduction is due entirely to curtailment of delivery truck operations.

*References are listed in Sec. 18.3.

could be used elsewhere if they were emptied on schedule. Furthermore, it is possible that delays in the delivery of gasoline to service stations may result in some stations running out of gasoline. Because of data limitations, these possible consequences of the action are not explicitly evaluated. Rather it it assumed that these impacts can be avoided through the rescheduling of deliveries and the use of overtime labor. Alternatively, some changes in the inventory or delivery practices prior to an episode might eliminate these adverse effects of the action.

Notification Cost

Notification of an episode is assumed to be made through radio and TV announcements. The cost of these announcements, derived in Appendix D, is $6,800/day, as shown in Table 18.1.

Rescheduling Cost

The rescheduling cost is estimated by assuming lower management personnel are responsible for scheduling pickups and deliveries of gasoline, and that 20 min. is needed to reschedule the activities of each vehicle (tank truck, railroad tank car, etc.) used to load and unload stationary storage facilities. The rescheduling cost for an n-day episode is thus:

$$C = (N \cdot W/504) \cdot n \qquad (18.1)$$

where:

$C \equiv$ the rescheduling cost,

$N \equiv$ the number of vehicles used per day,

$W \equiv$ the monthly wage of the persons responsible for scheduling, and

The constant 504 is the number of 20-min. periods in a working month of 21 eight-hour days.

In the Chicago area gasoline is transported by rail, truck, tanker, and pipeline [Refs. 2, 7]. Gasoline is usually shipped directly by pipeline from the refinery to storage tank farms, which usually have two days of excess storage capacity [Ref. 7]. Therefore, curtailment of unloading operations at the tank farm for less than two days most likely will not affect production. Because a detailed analysis of the entire gasoline production process and options available to oil refineries is beyond the scope of this study, it is

assumed that production is not affected for episodes of less than six days.* Gasoline is shipped from the tank farms to gasoline stations or other storage areas (bulk plants) within the study area by truck [Ref. 7]. Of the gasoline exported from the Chicago area (including Lake and Porter counties in Indiana), 50.8% is shipped by private truck or motor carrier, 47.6% by water, and the rest by rail [Ref. 2]. Tankers are often filled directly from the refinery by pipeline.

The number of vehicles used to transport gasoline each day in the Chicago area is estimated to be:

$$N = Q/Z_1 + \sum_{k=1}^{3} \bar{Q}_k/Z_k \qquad (18.2)$$

where:

$N \equiv$ the number of vehicles used to transport gasoline each day;

$Q \equiv$ the quantity of gasoline consumed in the Chicago SMSA (gal./day);

$Z_1 \equiv$ the average capacity of tanker trucks (gal./truck);

$k \equiv$ transportation mode: 1 = truck, 2 = rail, and 3 = water;

$\bar{Q}_k \equiv$ the quantity of gasoline exported from the area by mode k (gal./day); and

$Z_k \equiv$ the average capacity of export vehicles in mode k (gal./vehicle).

The average quantity of gasoline consumed each day must equal the average quantity of gasoline delivered to gasoline stations each day. The quantity of gasoline consumed is estimated as:

$$Q = \sum_{i=1}^{9} V_i/M_i \qquad (18.3)$$

*Oil refinery production may be reduced as a result of Action 10. However the degree to which oil refinery operations can be reduced is not clear. If oil refineries are allowed to operate during a red alert, then the unloading of gasoline at the tank farms may be allowed under the provision in Action 16 that unloading is prohibited *except* when an integral part of an industry operation allowed during a red alert. In this case, the cost of Action 16 is overestimated. On the other hand, if production is reduced, then the cost estimates are appropriate; however, they do not include the cost of reducing production.

where:

$Q \equiv$ the quantity of gasoline consumed in the Chicago SMSA (gal./day),

$V_i \equiv$ the vehicle miles traveled by vehicles of type i (miles/day), and

$M_i \equiv$ the average number of miles per gallon obtained by vehicles of type i.

The data for the nine vehicle types used in the analysis are provided in Table 18.2. Substituting these data into Eq. 18.3 results in an estimate of Q = 7,560,808 gal./day.

About 2.83 million tons/year of gasoline and jet fuel (SIC 29111) are exported from the Chicago area, including Lake and Porter counties in Indiana, to other regions of the country [Ref. 2]. This is an average of 7,764 tons/day. About 44.5% of the refining capacity in the eight-county area is in Illinois [Ref. 6]; therefore, in the Illinois portion of the region approximately 7,764 • 0.445 = 3,452 tons/day of gasoline and jet fuel are exported from the Chicago SMSA. It is assumed that all of this is gasoline. Gasoline weighs about 6.17 lbs/gal. [Ref. 4]; therefore, 3452 tons are equivalent to Q = 3,452 • 2,000/6.17 = 1,119,094 gal./day.

Table 18.2. Motor Vehicle Fuel Consumption in Chicago SMSA

Vehicle Type	Miles/Day[a]	Miles/Gal.	Gal./Day[b]
Automobiles	84,683,281	13.6[c]	6,226,712
Light Gasoline Trucks	2,986,120	10.0[c]	298,612
Heavy Gasoline Trucks	2,924,026	6.0[c]	487,338
Heavy Diesel Trucks	1,831,840	4.6[c]	398,226
Transit Buses	309,130	3.6[d]	85,869
School Buses	81,473	6.0[c]	13,579
Commercial Buses	161,600	6.0[c]	26,933
Motorcycles	1,412,325	60.0[e]	23,539

[a]Vmt estimates from Appendix E.

[b]Calculated by dividing miles/day by miles/gal.

[c]From Ref. 10.

[d]From Ref. 1, assuming CTA miles/gal. data are applicable to all transit buses in the region.

[e]Assumed value.

Since 50.8, 1.60, and 47.6% of the petroleum products are exported by truck, rail, and water (tankers), respectively, the values of $\overline{Q}_k$ are 568,500, 17,905, and 532,689 gal./day for k = 1, 2, and 3, respectively (for example, 568,500 = 0.508 • 1,119,094).

The value of Z_1 is set equal to 8,000 gal., the average capacity of a gasoline tank truck [Ref. 5]. Setting Z_2 = 8,000 gal. and Z_3 = 532,689 gal.* results in an estimate of N = 945 + 74 = 1,019 vehicles used daily. If $Z_1 = Z_2 = Z_3$ = 8,000 gal., the value of N would be 1,085. Since there is very little difference between these estimates, the more conservative one, N = 1,085, is used.

Substituting N = 1,085 and W = $1,416, the median income of a lower level management employee in metropolitan areas (i.e., Director of Personnel I in Table A.5), into Eq. 18.1 results in the estimated rescheduling costs given in Table 18.1.

Overtime Cost

The overtime cost is estimated by assuming each vehicle that transports gasoline is filled and emptied during an eight-hour work day. Therefore, the overtime cost for an n-day episode is:

$$\overline{C} = 0.5 \cdot N(\overline{W}/21 + \hat{W}/21) \cdot n \tag{18.4}$$

where:

$\overline{C}$ ≡ the overtime cost,

N ≡ the number of vehicles used per day,

$\overline{W}$ ≡ the monthly wage of the vehicle operator,

$\hat{W}$ ≡ the monthly wage of the storage facility operator,

The constant 21 is the number of days in a working month, and

The constant 0.5 reflects the assumption that the overtime rate is 1.5 times the normal wage rate.

In the previous section N was estimated to be 1,085 vehicles. The values of $\overline{W}$ and $\hat{W}$ are assumed to be equal to $840 (i.e., $5/hr, which is approximately the average wage of production workers in the Chicago SMSA in 1974). Substituting these data into Eq. 18.4 results in the estimated overtime costs provided in Table 18.1.

*It is assumed that on the average only one tanker is loaded each day.

18.2 EMISSION REDUCTION EFFECTS OF ACTION 16

The effectiveness of Action 16 is estimated from the following equations:

$$A = \sum_{k=1}^{3} \overline{Q}_k \cdot E_k + (Q_u - Q_m) \cdot E_1 + Q_u \cdot (E_u + E_g) \tag{18.5}$$

where:

$A \equiv$ emission reduction of hydrocarbons due to the curtailment of loading volatile organic material in quantities greater than 250 gal. (tons HC/day);

$k \equiv$ transportation mode: 1 = truck, 2 = rail, and 3 = water;

$\overline{Q}_k \equiv$ quantity of gasoline exported from the SMSA by mode k (gal./day);

$E_k \equiv$ emission rate of hydrocarbons from loading gasoline into vehicles of mode k (tons HC/gal.);

$Q_u \equiv$ quantity of gasoline unloaded at gasoline stations in the SMSA (gal./day);

$Q_m \equiv$ quantity of gasoline imported by trucks and unloaded at gasoline stations in the SMSA (gal./day);

$E_1 \equiv$ emission rate of hydrocarbons from loading gasoline into tanker trucks (tons HC/gal.);

$E_u \equiv$ emission rate of hydrocarbons from unloading gasoline trucks (tons HC/gal.); and

$E_g \equiv$ emission rate of hydrocarbons from loading underground tanks at gasoline service stations (tons HC/gal.).

and,

$$B_p = \overline{N} \cdot M \cdot \sum_{j=1}^{4} f_j \cdot E_p(S_j)/907{,}184 + G_p \tag{18.6}$$

where:

$B_p \equiv$ emission reduction of pollutant p due to the curtailment of delivery truck trips (tons/day);

$p \equiv$ pollutant: 1 = hydrocarbons, and 2 = nitrogen oxides;

$\overline{N} \equiv$ number of gasoline delivery trucks;

$M \equiv$ average daily mileage per delivery truck (miles/day);

$j \equiv$ traffic segment: 1 = expressway peak, 2 = expressway off-peak, 3 = arterial peak, and 4 = arterial off-peak;

$f_j \equiv$ fraction of delivery truck Vmt occurring during traffic segment j;

$E_p(S_j) \equiv$ emission rate of pollutant p for heavy diesel trucks at average speed S_j(tons HC/gal);

G_p ≡ evaporative emission reduction from reduced gasoline sales,*
The constant 1/907,184 converts grams to tons.

The total effectiveness of Action 16 is then:

$R_1 = A + B_1$ tons HC/day, and
$R_2 = B_2$ tons NO_x/day.

The following operations are included in the distribution of gasoline in the SMSA:

1. Loading and unloading large gasoline storage tanks. Most of the storage tanks in the SMSA are the floating roof type [Ref. 7], and loading and unloading this type of tank results in neglible HC losses [Ref. 4].

2. Loading gasoline trucks, tank cars, and marine vessels from large storage tanks. The Illinois regulation pertaining to loading organic material into vehicles [Rule 205(b)(1)] is as follows [Ref. 9]:

> No person shall cause or allow the discharge of more than 8 pounds per hour of organic material into the atmosphere during the loading of any organic material from the aggregate loading pipes of any loading facility having a through-put of greater than 40,000 gallons per day into any railroad tank car, tank truck or trailer unless such loading facility is equipped with submerged loading pipes or a device that is equally effective in controlling emissions and is approved by the Agency ...

An emission rate of 8 lbs/hr equals 192 lbs/day or 192 lbs per 40,000 gal. The emission rate is equivalent to 4.8 lbs HC/1000 gal. loaded. For submerged loading of railroad tank cars and trucks the U.S. EPA gives an emission rate of 4.1 lbs HC/1000 gal. loaded [Ref. 4]. Since data could not be collected on the number of submerged loading operations versus other controls, the average of the two emission rates was used of 4.45 lbs HC/

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*There are reduced sales of gasoline (diesel fuels) to tank truck operations, because of reduced miles traveled. It is assumed no reduction in gasoline sales to service station customers occurs due to this action.

1000 gal., i.e., $E_1 = E_2 = 4.45/(2000 \cdot 1000) = 2.225 \cdot 10^{-6}$ tons HC/gal. For loading marine vessels, the U.S. EPA gives an emission rate of 2.9 lbs HC/1000 gal. [Ref. 4], i.e., $E_3 = 2.9/(2000 \cdot 1000) = 1.45 \cdot 10^{-6}$ tons HC/gal.

3. Unloading gasoline tank trucks. The emission rate for unloading tank trucks is given by the U.S. EPA as 2.1 lbs HC/1000 gal. [Ref. 4] , i.e., $E_u = 2.1/(2000 \cdot 1000) = 1.05 \cdot 10^{-6}$ tons HC/gal.

4. Loading underground gasoline service station tanks. The Illinois air pollution regulation concerning the loading of any organic material into any stationary tank having a capacity greater than 250 gal. [Rule 205(b)(2); Ref. 9] requires that such a tank (a) be equipped with a permanent submerged loading pipe, or (b) is a pressure tank capable of withstanding the vapor pressure of such materials, so as to prevent vapor or gas loss to the atmosphere at all times, or (c) has a vapor gathering system capable of collecting 85% or more of the uncontrolled volatile organic material that would otherwise be admitted to the atmosphere. For tanks equipped as in (a), the U.S. EPA emission rate of 7.3 lbs HC/1000 gal. loaded for uncontrolled submerged loading [Ref. 4] is applicable. For tanks equipped as in (b), the emission loss would be negligible, as implied. For case (c), emissions would be 15% of the uncontrolled rate. Applying the U.S. EPA figure of 11.5 lbs HC/1000 gal. for uncontrolled splash loading of stationary tanks [Ref. 4], the resulting emission rate would be $0.15 \cdot 11.5 = 1.73$ lbs HC/1000 gal. The range of emission rates is 0 to 7.3 lbs HC/1000 gal., depending on the method of loading. Without data on the number of various types of controls in use, it is assumed the emission rate is midway -- or equal to 3.65 lbs/1000 gal., i.e., $E_g = 3.65/(2000 \cdot 1000) = 1.825 \cdot 10^{-6}$ tons HC/gal.

As discussed in Sec. 18.1, approximately 1,119,094 gal. of gasoline are exported daily from the SMSA, of which 50.8, 1.6 and 47.6% are transported by truck, rail, and tanker, respectively. The values for $\overline{Q}_k$ are 568,500, 17,905

and 532,689 gal./day for k = 1, 2, and 3, respectively. The average quantity of gasoline unloaded at gasoline stations in the SMSA is equal to the average quantity of gasoline delivered to gasoline stations each day which is equal to the average quantity of gasoline consumed each day. Gasoline consumption was estimated from Eq. 18.3 to be 7,560,808 gal./day in Sec. 18.1, i.e., Q_u = 7,560,808 gal./day. Data on the amount of imported gasoline were not acquired so estimates of upper and lower bounds were used to estimate emissions. A lower bound is zero imports; an upper bound in imports is equal to the ratio of the quantity of gasoline refined in Lake and Porter counties in Indiana to the total quantity refined in the Chicago SMSA and Lake and Porter counties in Indiana, i.e., 0.555, times the regional consumption of gasoline (see Eq. 18.3). The resulting upper bound estimate for Q_m is 7,560,808 • 0.555 = 4,196,248 gal./day. Assuming a value midway in the range, the value of Q_m is 2,098,124 gal./day. Substituting the values of $\overline{Q}_k$, Q_u, Q_m, E_k, E_u, and E_g into Eq. 18.5 results in an estimate of the evaporative hydrocarbon emission reduction of:

$$A = 36.0 \text{ tons HC/day}$$

In addition, emission reductions occur from the elimination of gasoline delivery truck travel. There are approximately 945 such trucks operating in the SMSA ($\overline{N}$ in Eq. 18.6 is equal to Q/Z in Eq. 18.2). The average amount of travel by vehicles in the CATS heavy truck category is estimated at 29.6* miles/day, assumed to apply to gasoline delivery trucks (M in Eq. 18.6). The Vmt of gasoline delivery trucks is 945 • 29.6 = 27,972 miles/day. Assuming that this traffic occurs during off-peak hours with 25.9% on expressways and 74.1% on arterials,** then the f_j values in Eq. 18.6 would equal 0/0.259/0/0.741. Applying heavy diesel truck emission factors for the off-peak traffic segments from Tables E.4 and E.5, the estimated emission reductions from curtailing truck travel would be:

B_1 = 0.106 tons HC/day, and
B_2 = 0.758 tons NO_x/day.

*CATS data indicate there are 219,692 heavy trucks in the eight county CATS study area driving a total of 6,503,791 miles/day on internal trips [Ref. 11]. The average amount of travel for heavy trucks is then 29.6 miles/day.

**CATS data indicate that 25.9% of all traffic occurs on expressways and 74.1% on arterials [Ref. 8]. These data are assumed to apply to gasoline delivery truck travel.

The hydrocarbon evaporative emission reduction, G_1, is estimated in Appendix G to be 0.0385 tons HC/day. The value of G_2 is equal to zero. The total effectiveness of Action 16 is, therefore:

$R_1 = 36.0 + 0.106 + 0.0385 = 36.1$ tons HC/day, and

$R_2 = 0.758$ tons NO_x/day.

18.3 REFERENCES

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19 PROHIBITION OF REFUSE INCINERATION -- ACTION 17

During an ozone red alert or emergency all waste incineration is prohibited. For the reasons discussed in Chapter 8 (Action 6), the cost/effectiveness analysis for the municipal/commercial incinerators is restricted to the incinerators presently operated by the City of Chicago. The costs and effects of prohibiting waste incineration are summarized in Table 19.1.

19.1 COSTS OF ACTION 17

The costs to the small refuse incinerators are assumed to be identical to those discussed in Chapter 8. To estimate the costs of closing the larger municipal incinerators it is assumed that all waste collected after the incinerators' storage capacity is exceeded must be landfilled. In addition, the

Table 19.1. Summary of the Costs and Emission Reduction Effects of Prohibiting Refuse Incineration

Episode Length (days)	Costs (10^3): Notification: Small Incin.[a]	Notification: Mun./Comm.[b]	Landfill: Small Incin.[a]	Landfill: Mun./Comm.	Rescheduling (Mun./Comm.)	Shut-Down, Start-Up (Mun./Comm.)	Overtime for Collect.	Total
1	6.80	0.002	1.08	1.62	1.21	11.6	34.5	56.8
2	13.6	0.002	2.16	3.67	2.41	21.6	96.6	140
3	20.4	0.002	3.24	5.02	3.62	31.5	138	202
4	27.2	0.002	4.32	7.08	4.83	41.5	200	285
5	34.0	0.002	5.40	8.43	6.04	51.5	242	347

Table 19.1. (Cont'd)

Episode Length (days)	HC Emission Reductions (tons): Small Incin.[a]	HC: Mun./Comm.	HC: Collect. Trucks	HC: Total	NO_x Emission Reductions (tons): Small Incin.[a]	NO_x: Mun./Comm.	NO_x: Collect. Trucks	NO_x: Total
1	9.00	1.82	0.184	11.0	2.50	3.07	0.785	6.36
2	18.0	3.64	0.368	22.0	5.00	6.14	1.57	12.7
3	27.0	5.46	0.552	33.0	7.50	9.21	2.36	19.1
4	36.0	7.28	0.736	44.0	10.0	12.3	3.14	25.4
5	45.0	9.10	0.920	55.0	12.5	15.4	3.93	31.8

[a]From Table 8.1.

[b]Mun./Comm. = Municipal and Commercial Incinerators.

large incinerators cannot be shut down completely; they must be operated at a minimum level to avoid damage to equipment. Furthermore, the City of Chicago has contractual commitments to provide steam from some of its incinerators to other facilities. The use of supplemental fuels is therefore required to ensure that there is no damage to equipment and that contractual commitments are met. Three to eight hours are needed after operations are resumed to bring the incinerators back to operating capacities, which has the effect of lengthening the shut-down time.

Although waste collection activities are not curtailed by this action, officials at the City of Chicago's Department of Streets and Sanitation anticipate that waste collection activities would be curtailed as a means of effectively adjusting to the closing of the incinerators. Therefore, it is not clear whether the costs of delaying waste collection would be allocated to the costs of closing incinerators or to some other episode action. In this analysis these costs are assigned to the closing of incinerators, Action 17.

The estimated costs of closing municipal incinerators are those of: (1) notifying incinerator operators of the alert or emergency, (2) rescheduling incineration/storage/landfill operations, (3) shutting down and starting up the incinerators, (4) landfilling excess waste, and (5) collecting wastes not picked up during the red alert. The data, assumptions, and methods used to estimate these costs are discussed below.

Notification Cost

It is assumed that each of the waste incinerator operators is notified by telephone by the superintendent of the Department of Streets and Sanitation that an episode has been called and that they must cease operations. Assuming each call lasts two minutes, the notification cost is estimated to be:

$$C = N \cdot (T + W/624{,}000 + \overline{W}/5{,}040) \qquad (19.1)$$

where:

$C \equiv$ the cost of notifying the incinerator operators,

$N \equiv$ the number of incinerators,

$T \equiv$ the cost of a telephone call,

$W \equiv$ the annual salary of the superintendent,

$\overline{W} \equiv$ the monthly salary of a plant operator, and

The constants 624,000 and 5,040 are the number of two-minute periods in a working year (260 eight-hour days) and month (21 eight-hour days). respectively.

The City of Chicago operates three incinerators during the summer months [Ref.1];* therefore N = 3. The annual salary (W) of the superintendent of the Department of Streets and Sanitation is $23,820 [Ref.1], which is $20,867 in 1974 dollars. A plant manager's monthly salary ($\overline{W}$) in 1974 dollars is assumed to be $1,170, which which is the medium salary of a Class II Engineer (see Table A.5). If T = $0.10, then, from Eq. 19.1, C = $2.00. Assuming the telephone calls only occur on the first day of the episode results in the municipal/commercial notification costs in Table 19.1.

Rescheduling Cost

The rescheduling costs for a complete shutdown are assumed to be twice the rescheduling costs calculated for Action 6. These costs for an n-day episode are:

$$\overline{C} = (\$41.79 \cdot 2) \cdot n \tag{19.2}$$

In addition, waste collection operations must be rescheduled. For an n-day episode this rescheduling cost is estimated to be:

$$\tilde{C} = (\tilde{N} \cdot \tilde{W} \cdot \alpha / 10{,}080) \cdot n \tag{19.3}$$

where:

$\tilde{C} \equiv$ the rescheduling cost,

$\tilde{N} \equiv$ the number of vehicles requiring rescheduling,

$\tilde{W} \equiv$ the monthly wage rate of the person doing the rescheduling,

$\alpha \equiv$ the average number of minutes required for rescheduling each truck, and

The constant 10,080 is the number of minutes in a working month of 21 eight-hour days.

The refuse in Chicago is collected by approximately 400 work crews [Ref. 1]. Assuming one truck is used per crew, then $\tilde{N}$ = 400. If the rescheduling is done by lower level management personnel, then $\tilde{W}$ = $1,416/month (see Director of Personnel I in Table A.5). Setting α = 20 results in a rescheduling cost for work collection crews of:

$$\tilde{C} = \$1{,}124 \cdot n \tag{19.4}$$

*References are listed in Sec. 19.4.

The sum of the incinerator operations rescheduling cost (Eq. 19.2) and the waste collection rescheduling cost (Eq. 19.4) results in the total rescheduling costs provided in Table 19.1.

Shut-Down and Start-Up Cost

The cost of the supplemental fuels required to prevent equipment damage or supply steam to other facilities represents the cost of shutting down an incinerator. The supplemental fuel costs are summarized in Table 19.2; from these data the total daily cost of shutting down the three Chicago incinerators is $0.876 \cdot [10 + (24 + 213 + 237) \cdot 24] = \$9,974$/day. (The factor 0.876 converts the 1976 dollar figures into 1974 dollars.)

It takes three hours for the Calumet plant and eight hours for the other two plants to be brought up to normal operating levels. Assuming a uniform build-up of operations and that heat requirements must be uniform throughout the day, then half of the heat requirements during the build-up period would be supplied by supplemental fuels. The fuel costs during start-up are: $0.876 \cdot (24 \cdot 3 + 213 \cdot 8 + 237 \cdot 8)/2 = \$1,608$. (This is an overestimate since the minimum heat requirement is less than the heat generated by normal operating levels of the incinerator, i.e., the full build-up period is not required before minimum heat requirements can be generated from burning of the refuse.)

Table 19.2. Supplemental Fuel Costs

Incinerator	Cost (1976 $)	Purpose
Calumet	$10/day	Electricity for stand-by pumps and lighting.
Calumet	$24/hr	Fuel oil to keep package boiler on line and to prevent freeze up.
Southwest	$213/hr	For oil to provide 72,000 lbs. of steam per hour (60,000 exported).
Northwest	$237/hr	Gas to provide 100,000 lbs. of steam per hour.

Source: Ref. 3.

The effects of the lost capacity during the start-up period are included in the landfill cost calculation. To avoid double counting these costs are not included here. Therefore, the shut-down and start-up cost for an n-day episode is:

$$\hat{C} = 9{,}974 \cdot n + 1{,}608 \tag{19.5}$$

The values of $\hat{C}$ for various length episodes are provided in Table 19.1.

Landfill Cost

Information on the average quantity of refuse incinerated, incinerator capacity, and storage capacity for each of the Chicago incinerators is provided in Table 19.3. These data imply an average operating schedule for collection, incineration, storage, and landfill, as shown in Table 19.4. If waste collection is curtailed when incineration operations are stopped, then during average conditions no additional landfilling of waste would be required. Even if maximum waste generation of 30,000 tons/week [Ref. 1] occurred simultaneously with an episode and the following week was average or below average for waste generation, then no additional landfilling of wastes would be required.

However, if successive weeks of high waste generation occur simultaneously with an episode, then additional landfilling of wastes would be required. Peak waste generation periods result in a schedule of operations as shown in Table 19.5. The expected quantity of waste landfilled during peak periods and without an episode is 4,700 tons/week. The additional quantities of waste landfilled because of an episode of various lengths can be as great as the estimates shown in Table 19.6.

Table 19.3. Incinerator Characteristics in Chicago

Incinerator	Avg. Waste Incin. (tons/day)	Capacity (tons/day)	Storage Capacity (tons/day)
Calumet	900	1,000	1,800
Southwest	550	1,200	2,000
Northwest	1,020	1,600	2,500
TOTAL	2,470	3,800	6,300

Source: Ref. 3.

Table 19.4. Average Summer Operating Schedule for Chicago Incinerators

Day	Tons of Solid Waste				
	Collected	Incinerated[a]	Stored	Cum. Storage[b]	Landfilled
Monday	3,458	2,470	988	988	0
Tuesday	3,458	2,470	988	1,976	0
Wednesday	3,458	2,470	988	2,964	0
Thursday	3,458	2,470	988	3,952	0
Friday	3,458	2.470	988	4,940	0
Saturday	0	2,470	-2,470	2,470	0
Sunday	0	2,470	-2,470	0	0
TOTAL	17,290	17,290	0	--	0

[a]Maximum incineration = 3,800 tons/day.

[b]Maximum cumulative storage = 6,300 tons.

Table 19.5. Peak Operating Schedule for Chicago Incinerators

Day	Tons of Solid Waste				
	Collected	Incinerated[a]	Stored	Cum. Storage[b]	Landfilled
Monday	6,000	3,800	2,200	2,200	0
Tuesday	6,000	3,800	2,200	4,400	0
Wednesday	6,000	3,800	1,900	6,300	300
Thursday	6,000	3,800	0	6,300	2,200
Friday	6,000	3,800	0	6,300	2,200
Saturday	0	3,800	-3,800	2,500	0
Sunday	0	2,500	-2,500	0	0
TOTAL	30,000	25,300	0	--	4,700

[a]Maximum incineration = 3,800 tons/day.

[b]Maximum cumulative storage = 6,300 tons.

The results in Table 19.6 are obtained by assuming waste collection. is curtailed during an episode and made up during weekends. Furthermore, maximum waste generation of 30,000 tons/week is assumed to occur for at least the period of time required to recover from the effects of the episode. The results are generated by developing schedules of collection, incineration, storage, and landfill which are interrupted by a red alert or emergency of various lengths. The schedule reflects the length of the episode and the

Table 19.6. Additional Waste Requiring Landfill

Episode Length (days)	Additional Waste Landfilled (tons)
1	3,001
2	6,801
3	9,301
4	13,101
5	15,601

lost capacity of 13.2% during the start-up period (i.e., $[(3 + 8 + 8)/2]/(3 \cdot 24) = 0.132$). From these schedules the total quantity of waste landfilled in case of an episode is calculated. Subtracting the quantity of waste that would have been landfilled without the episode yields the tons of waste landfilled due to the episode. For example, Table 19.7 is the schedule developed for a two-day episode; the results are independent of the day that the episode begins. Table 19.7 provides the total quantity of waste landfilled during the two-week period, i.e., 16,201 tons. Without the episode, $2 \cdot 4{,}700 = 9{,}400$ tons of waste would have been landfilled. Therefore, 6,801 additional tons of waste are landfilled.

The average cost of landfilling waste in the Chicago area was \$4.25/ton in 1970 dollars [Ref. 4], which is equivalent to a cost of \$5.40/ton in 1974 dollars. Defining L_n as the additional tons of waste landfilled due to an n-day episode, then the landfill cost of an n-day episode is estimated as:

$$C' = 5.40 \cdot L_n \cdot \alpha \tag{19.6}$$

The variable α is the likelihood of an episode occurring during a period of high waste generation. Data are not presently available to estimate α. For this analysis it was set equal to 0.1, which is considered to be high. Because the landfill cost is relatively low, the actual value of α is not very important. A summary of the landfill costs is provided in Table 19.1.*

*There are no savings of operating costs of the incinerators that one might expect from the reduced quantity of waste incinerated. The reason is that the incinerators must still be manned even if waste is not being burned.

Table 19.7. Peak Operating Schedule during a Two-Day Episode

Day	Tons of Solid Waste				
	Collected	Incinerated[a]	Stored	Cum. Storage[b]	Landfilled
Monday[c]	0	0	0	0	0
Tuesday[c]	0	0	0	0	0
Wednesday	6,000	3,299[d]	2,701	2,701	0
Thursday	6,000	3,800	2,200	4,901	0
Friday	6,000	3,800	1,399	6,300	801
Saturday	6,000	3,800	0	6,300	2,200
Sunday	6,000	3,800	0	6,300	2,200
Monday	6,000	3,800	0	6,300	2,200
Tuesday	6,000	3,800	0	6,300	2,200
Wednesday	6,000	3,800	0	6,300	2,200
Thursday	6,000	3,800	0	6,300	2,200
Friday	6,000	3,800	0	6,300	2,200
Saturday	0	3,800	-3,800	2,500	0
Sunday	0	2,500	-2,500	0	0
TOTAL	60,000	44,300	0	--	16,201

[a]Maximum incineration = 3,800 tons/day.

[b]Maximum cumulative storage = 6,300 tons.

[c]Episode day.

[d]Loss of 13.2% capacity during start-up period: 3,800•(1 - .1319).

Overtime Adjustment Costs

Wastes that are not collected during an episode are assumed to be picked up during weekends. The cost of collecting waste is 1.5 times as expensive on Saturdays and 2.0 times as expensive on Sundays as the cost of collection on weekdays [Ref. 1]. This implies the additional waste collection costs are:

$$C'' = Z\cdot(0.5\cdot T_1 + 1.0\cdot T_2) \qquad (19.7)$$

where:

C'' ≡ the additional waste collection costs,

Z ≡ the average cost per ton of waste collected during the week,

T_1 ≡ the expected tons of waste collected on Saturday, and

T_2 ≡ the expected tons of waste collected on Sunday.

The average waste collection cost, Z, in the Chicago area is $27.94/ton in 1974 dollars. (The cost of $22/ton in 1970 dollars was obtained from Ref. 4. This figure is converted to 1974 dollars by multiplying it by 1.27). The values of T_1 and T_2 are provided in Table 19.8. Substituting these values of Z, T_1, and T_2 into Eq. 19.7 yields the estimated waste collection costs shown in Table 19.1.*

19.2 EMISSION REDUCTION EFFECTS OF ACTION 17

The average emissions from waste incinerators are 1.5 lbs HC/ton of waste and 3.0 lbs NO_x/ton of waste [Ref. 2]. The average quantity of waste incinerated each day during the summer in Chicago is about 2,470 tons [Ref. 3].

Table 19.8. Required Saturday and Sunday Waste Collection for Episodes of Various Lengths

Episode Length in Days & Day of Collection		Tons of Waste Collected on Sat. or Sun., According to Day on Which Episode Begins							Expected Weekend Collection (tons/day)	
		Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.	Sun.	T_1	T_2
1	Sat.	3,458	3,458	3,458	3,458	3,458	0	0	2,470	--
1	Sun.	0	0	0	0	0	0	0	--	0
2	Sat.	3,458	3,458	3,458	3,458	3,458	0	3,458	2,964	--
2	Sun.	3,458	3,458	3,458	3,458	0	0	0	--	1,976
3	Sat.	6,916	6,916	6,916	3,458	3,458	3,458	3,458	4,940	--
3	Sun.	3,458	3,458	3,458	3,458	0	0	3,458	--	2,470
4	Sat.	6,916	6,916	6,916	3,458	3,458	3,458	6,916	5,434	--
4	Sun.	6,916	6,916	3,458	3,458	3,458	3,458	6,916	--	4,446
5	Sat.	10,374	6,916	6,916	6,916	6,916	6,916	6,916	7,410	--
5	Sun	6,916	6,916	3,458	3,458	3,458	3,458	6,916	--	4,940

*Using the method of calculating overtime of solid waste collection in Chapter 16 (i.e., Eq. 16.6) the overtime cost would be $32,000/day rather than the $34,500/day calculated using Eq. 19.7. The similarity of these numbers increases the confidence placed in them.

Therefore, the expected summer's day emissions from the incinerators in Chicago are $2{,}470 \cdot 1.5/2{,}000 = 1.85$ tons of HC and $2{,}470 \cdot 3/2{,}000 = 3.71$ tons of NO_x.

The Illinois EPA emission inventory lists average annual emission rates for the three Chicago incinerators of 603.9 tons of HC and 888.6 tons of NO_x. These imply average daily emission rates of 1.66 tons of HC and 2.44 tons of NO_x. Since waste generation peaks during the summer months, the emission rates calculated using the emission factors from Ref. 2 seem appropriate for this analysis.

Based on the data provided by Mr. Degnan [Ref. 3], it is estimated that about 750.5 gal. oil/hour and 134,000 ft^3 natural gas/hour will be required to avoid damage to equipment and to satisfy contractural commitments for steam if the incinerators are closed. Using appropriate emission factors for fuel oil and natural gas, provided in Ref. 2, the emissions of HC and NO_x from the use of these supplemental fuels are:

$$(0.7505 \cdot 3 + 0.134 \cdot 3) \cdot 24/2{,}000 = 0.032 \text{ tons HC/day, and}$$
$$(0.7505 \cdot 40 + 0.134 \cdot 175) \cdot 24/2{,}000 = 0.642 \text{ tons } NO_x\text{/day.}$$

The net reductions in emissions from closing down the Chicago incinerators are:

$$R_1 = 1.85 - 0.032 = 1.82 \text{ tons HC/day, and}$$
$$R_2 = 3.71 - 0.642 = 3.07 \text{ tons } NO_x\text{/day.}$$

There are also emission reductions realized by the curtailment of the waste collection activities. There are about 400 crews used to collect waste each day [Ref. 1], and therefore, about 400 diesel-powered trucks used each day to collect wastes, which travel about 60 miles daily. Assuming that all of this travel occurs on arterial streets during off-peak periods, and that the trucks idle for six hours of an eight-hour workday (i.e., travel at extremely slow speeds) while collecting refuse, then the reduction in emissions from curtailing waste collection for a day is:

$$\overline{R}_1 = 0.151 \text{ tons of HC/day, and}$$
$$\overline{R}_2 = 0.785 \text{ tons of } NO_x\text{/day.}$$

The curtailment of waste collection activities also results in a reduction of evaporative hydrocarbon emissions of 0.0330 tons/day (see Appendix G). Therefore, the total hydrocarbon emission reduction resulting from the curtailment of waste collection activities is:

0.151 + 0.0330 = 0.184 tons HC/day.

A summary of the emission reduction effects of Action 17 is provided in Table 19.1.

19.3 SENSITIVITY ANALYSIS FOR ACTION 17

The landfill, rescheduling, and overtime costs are affected by the assumption that waste collection is curtailed when the incinerators are closed down. If waste collection is not affected by the episode regulation, then the overtime costs become zero, and the sum of the landfill and rescheduling costs becomes \$84, \$3,227, \$13,037, \$22,372, and \$33,120 for episodes of one to five days in length, respectively.

Table 19.9 summarizes the effects of the waste collection assumption on the cost of Action 17. These effects can be interpreted as the cost of curtailing waste collection activities over and above the costs of closing down incinerators.

The efficiency of Action 17 is also affected by the inclusion of waste collection costs. Table 19.10 presents the cost/effectiveness ratios for

Table 19.9. Effect of Waste Collection Curtailment Assumption on the Cost Estimate of Closing Incinerators

Type of Costs	Costs by Length of Episode ($\$10^3$) 1 Day	2 Days	3 Days	4 Days	5 Days
With Assumption					
Rescheduling	1.21	2.41	3.62	4.83	6.04
Landfill	1.62	3.67	5.02	7.08	8.43
Waste Collection	34.5	96.6	138	200	242
Subtotal A	37.3	103	147	212	256
Without Assumption					
Rescheduling	0.034	0.167	0.251	0.344	0.418
Landfill	0	3.06	12.8	22.0	32.7
Waste Collection	0	0	0	0	0
Subtotal B	0.034	3.23	13.1	22.3	33.1
Effect of Assumption (A-B)	37.2	99.8	134	190	223

Table 19.10. Efficiency of Action 17 for a One-Day Episode

Operations Affected	Cost/Effectiveness Ratios ($\$10^3$/ton) HC	NO_x
Large & Small Incinerators & Waste Collection	5.16	8.93
Large & Small Incinerators & No Waste Collection	1.81	3.52
Large Incinerators & Waste Collection	24.4	12.7
Large Incinerators & No Waste Collection	6.45	3.82
Small Incinerators	0.880	3.17
Waste Collection Only	202	47.4

Action 17 under various assumptions. It is clear from these data that the most efficient part of Action 17 is the control of small incinerators and the least efficient aspect is the control of waste collection operations.

19.4 REFERENCES

1. Callahan, Supt. J.F., and E.F. Nigro, City of Chicago Department of Streets and Sanitation, personal communications (1976).

2. *Compilation of Air Pollution Emission Factors,* U.S. EPA, AP-42 (March 1975).

3. Degan, F.J., Acting Commissioner, City of Chicago Department of Streets and Sanitation, personal communication (Sept. 27, 1976).

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20 CURTAILMENT OF MOTOR VEHICLE OPERATIONS -- ACTION 18

During an ozone emergency, motor vehicle operations in or into the affected area are prohibited except for essential uses such as police, fire, and health services, and comparable uses designated by the Illinois Emergency Highway Traffic Regulations Plan. This action is highly correlated with other actions because the curtailment of motor vehicle operations implies that most employees and patrons of commercial, retail, manufacturing, and other establishments will not be able to travel far from their homes.* Therefore, for all practical purposes, Action 18 will also result in the curtailment of most other activities in the affected area.

For the purpose of this analysis, it is assumed that activities cease in mining and quarrying (10-14);** contract construction (15-17); manufacturing (20-39); transportation and utility (40-49) except for electric power generation, natural gas supply, water supply, and sewage operations; wholesale trade (50-51); retail trade (52-59); finance, insurance, and real estate (60-69); and service industries (70-89). Reduced government activities are reflected in the closing of the above establishments.

Electric power generation, natural gas supply, water supply, sewage, and police, fire, and health services are assumed to be essential and are therefore exempt from the regulation. Airport operations are assumed to be curtailed because pilots, mechanics, air traffic controllers, etc., cannot get to the airport. It could be assumed that these airline and airport employees would be exempt from Action 18 and that air traffic would not have to be curtailed, although passengers enroute to and from Chicago would be affected. For simplicity, it was decided not to exempt airline and airport employees.

Defining the scope of Action 18 in this way results in the costs and emission reduction effects shown in Table 20.1.

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*Note that mass transit vehicles are *not* exempt from Action 18. Therefore, the only means of travel in the affected area are walking, bicycling, horseback riding, etc.

**Numbers in parentheses are Standard Industrial Classification (SIC) codes.

Table 20.1. Summary of the Costs and Emission Reduction Effects of Curtailing Motor Vehicle Operations

Episode Length (days)	Costs ($\$10^3$)										
	Notification	Rescheduling	Shut-Down, Start-Up	Overtime[a]	Delay	Spoilage	Landfill	Traffic Diversion	Canceled Trips	Detainment	Total
1	736	652	3,820	27,800	203	107	2.70	1,080	1,140	405	35,900
2	1,470	1,290	3,830	53,000	559	214	5.83	2,160	2,280	1,210	66,000
3	2,210	1,930	3,840	78,300	1,070	321	8.26	3,240	3,420	2,430	96,800
4	2,940	2,570	3,850	104,000	1,710	429	11.4	4,320	4,570	4,050	128,000
5	3,680	3,210	3,860	129,000	2,560	536	13.8	5,400	5,710	6,070	160,000

Table 20.1 (Cont'd)

Episode Length (days)	HC Emission Reductions (tons)			NO_x Emission Reductions (tons)		
	Vehicular Sources	Stationary Sources	Total	Vehicular Sources	Stationary Sources	Total
1	774	710	1,480	504	325	829
2	1,550	1,420	2,970	1,010	650	1,660
3	2,320	2,130	4,450	1,510	975	2,490
4	3,090	2,840	5,930	2,020	1,300	3,320
5	3,870	3,550	7,420	2,520	1,630	4,150

[a]The overtime costs are functions of the expected frequency and duration of an emergency. If this action is used for a yellow or red alert, the overtime cost estimates may change. However, the results here are maximum costs of Action 18 for alert stages called at ozone concentrations <0.5 ppm and are appropriate for all alert stages called at ozone concentrations $\geq$0.5 ppm.

20.1 COSTS OF ACTION 18

The costs of Action 18 include those of notification, rescheduling, shut-down/start-up, overtime adjustment, delay, spoilage, diversion of through traffic, canceled trips, and detainment resulting directly or indirectly from the curtailment of motor vehicle operations.

Notification Cost

All large establishments that may be closed because workers or patrons cannot travel to them are assumed to be notified by telephone of the emergency. Table 20.2 summarizes the telephone notification costs for the various establishments contacted; these costs have been calculated in previous chapters. The cost of notifying automobile passengers who do not reside with the driver does not come directly from any of the previous chapters. For other actions only a fraction of the automobile trips is curtailed, but for this action all trips are postponed, affecting 2.864 million passengers. Assuming that half of the automobile passengers reside with the driver results in the estimated automobile passenger notification cost listed in the table.

Table 20.2. Daily Telephone Notification Cost of Action 18

Those Notified	No. of Calls	Cost ($)
Airline Companies (21)[a]	32	22
Airline Passengers (21)	130,346[b]	73,552
Auto Passengers (3, 10, 24)	1,432,000[c]	620,533
Commercial Establishments (24)	156	103
Fleet Operations (9)	132	87
Government Offices (11, 16)	242	160
Incinerator Operators (19)	3	2
Manufacturing Firms (12, 22)	196	130
Parking Lot Operators (10)	417	276
School Superintendents (17)	302	200
TOTAL	1,563,826	695,065

[a]Numbers in parentheses indicate chapters from which information is obtained.

[b]Each passenger is assumed to be called twice: to cancel old reservation and to make a new reservation.

[c]It is assumed that 50% of the passengers of all non-home trips do not reside with the driver.

The public is assumed to be notified of the emergency through radio and TV announcements. For announcements averaging ten seconds, this cost is $6,800/day, as derived in Appendix D. Because of the importance of curtailing all traffic, it is assumed the average announcement lasts one minute. Therefore, the radio and TV announcement cost is $6,800 • 6 = $40,800/day.

Assuming the telephone calls are made each day to ensure proper enforcement of the action, the total notification cost becomes $695,065 + 40,800 = $735,856/day, as shown in Table 20.1.

Rescheduling Costs

After an episode, the management of airline companies, commercial establishments, government agencies, incinerator operations, manufacturing establishments, transport companies, and utility companies must reschedule some of their employees, vehicles, and/or production schedules. The rescheduling cost for one day's curtailment of activities in each of these establishments is provided in Table 20.3; details on the estimating procedure may be found in previous chapters, as indicated in the table.

Table 20.3. Rescheduling Cost of Action 18 for One Day's Curtailment of Activities

Those Rescheduling Activities	Cost ($)
Airline Companies (21)[a]	9,043
Commercial Establishments (24)	265,569
Government Agencies (11)	1,020
Government Trucking Operations (16)	28,873
Incinerator Operators[b] (8, 19)	84
Manufacturing Establishments (22)	220,542
Transportation and Utility Vehicles[c] (9, 18)	113,568
TOTAL[d]	638,699

[a]Numbers in parentheses indicate chapters from which information is obtained

[b]Rescheduling of solid waste collection trucks not included.

[c]Assuming that rescheduling is only required for vehicles in fleets of more than two vehicles. The gasoline tank trucks are assumed to be in large fleets; therefore, they are included in the rescheduling cost for Action 7.

[d]Large manufacturing firms are assumed to require one day to start up operations after an episode; therefore, the rescheduling cost of an n-day episode is $\$638,699 \cdot n + \$13,216$.

Large manufacturing plants are assumed to need one day to start up operations after an episode; therefore, they must reschedule an additional day. The rescheduling cost for the large manufacturing plants is $13,216/day (see Chapter 12), and the total rescheduling cost of Action 18 for an n-day episode, as shown in Table 20.1, is:

$$C = 638,699 \cdot n + 13,216 \tag{20.1}$$

Shut-Down/Start-Up Cost

Airline companies, incinerator operators, manufacturing firms, and transportation and utility companies will incur a shut-down/start-up cost as a result of Action 18. Table 20.4 summarizes these costs, most of which have been derived in previous chapters.

All trucks that haul freight long distances (e.g., interstate trucks) are affected by Action 18. If it is assumed that half of the 40,822 trucks that have origins or destinations outside the Chicago SMSA fall into this category, then 20,411 trucks will incur shut-down/start-up costs. Since

Table 20.4. Shut-Down and Start-Up Cost of Action 18

Operation Affected	Cost ($) Daily	One-Time
Airline Activities (21)[a]	--	446,429
Incinerator Operations (19)	9,974	1,608[b]
Manufacturing Firms (22)	--	2,851,800
Transportation and Utility Vehicles	--	510,275[c]
TOTAL	9,974	3,810,112

[a]Numbers in parentheses indicate chapters from which information is obtained.

[b]A daily cost occurs because supplemental fuels are required to keep equipment from being damaged.

[c]All interstate trucks are assumed to incur shut-down and start-up costs, i.e., 20,411 trucks.

6,748 of these trucks are affected by Action 7 and the shut-down/start-up cost for Action 7 is $168,700 (see Chapter 9), this cost for Action 18 is (20,411/ 6,748) • 168,700 = $510,275.

For most activities it was assumed, for lack of any data, that the shut-down and start-up cost is independent of the length of the episode, i.e., the plant, store, etc., has to be shut down at the beginning of the episode and started up at the end of the episode. For municipal waste incinerators supplemental fuels are required during the shut-down period to avoid damage to equipment. Therefore, there is a daily cost associated with shutting down and starting up municipal incinerators, as indicated in Table 20.4.

The shut-down and start-up cost for an n-day episode is, as shown in Table 20.1:

$$\overline{C} = 9{,}974 \cdot n + 3{,}810{,}112 \qquad (20.2)$$

Overtime Adjustment Cost

The overtime adjustment is preferred to the inventory adjustment (see Chapters 12 and 22). Overtime costs are borne by the industries listed in Table 20.5 to avoid losses in output that could result from lost working days during an episode; most of these costs have been derived in previous chapters.

Table 20.5. Overtime Adjustment Cost for Action 18

SIC Code	Industry	One-Day Cost ($)
10-14	Mining and Quarrying (24)[a]	88,000
15-17	Contract Construction (24)	3,582,000
20-39	Manufacturing (22)	13,321,000[b]
40-49	Transportation and Utilities	2,556,000[c]
4953	Waste Collection Trucks (16)	64,000
50-51	Wholesale Trade (24)	5,129,000
722, 7395	Photographic Studios (24)	66,000
731	Advertising Agencies (24)	295,000
733	Mailing, Reproduction, etc. (24)	102,000
7397	Commercial Testing Labs (24)	31,000
	TOTAL	25,234,000[d]

[a] Numbers in parentheses indicate chapters from which information is obtained.

[b] Includes dry cleaners and laundries (SIC 721).

[c] Includes overtime for *all* non-government trucks and utility automobile fleets except those used for emergencies or personal use, including those used to deliver gasoline (Chapter 18).

[d] It is assumed large manufacturing firms require one day after an episode to start up operations. Since $2,577,000 of the overtime for manufacturers is from large firms, the overtime adjustment cost of Action 18 of an n-day episode is: $25,234,000•n + $2,577,000.

A major difference between Action 7 and Action 18 is the overtime cost for trucks. For Action 7, only non-government trucks in fleets of three or more vehicles are considered. For Action 18, *all* non-government trucks* not used for personal or emergency use are assumed to be affected and the overtime adjustment cost is estimated as:

$$\hat{C} = 0.5 \cdot \hat{W} \cdot H \qquad (20.3)$$

where:

$\hat{C}$ ≡ the overtime cost,

$\hat{W}$ ≡ the average hourly wage rate of truck drivers,

*Government trucks activities such as mail deliveries are assumed to be made up without overtime. Overtime costs for solid waste collection activities are estimated separately.

$H \equiv$ the number of man-hours lost due to an episode, and

The constant 0.5 reflects the assumption that on the average, the overtime rate is 1.5 times the normal wage rate.

The total number of non-government trucks operating daily in the Chicago SMSA is 179,859 (see Chapter 9). Approximately 55,397, or 30.8%,* of these are used for personal use and 452 are used by utilities for emergency purposes. Therefore, 179,859 - 55,397 - 452 = 124,010 non-government trucks are affected by Action 18. If one-man day is assumed to be lost per vehicle per episode day, and the overtime adjustment is used for all non-government trucks not used for personal use or emergencies, and for utility automobile fleets, then $H = 8 \cdot (124,010 + 3,790) = 1,022,400$. The constant 8 is the number of man-hours in a man-day and 3,790 is the number of utility automobiles not used for emergencies (see Chapter 9). The value of $\hat{W}$ is assumed to be \$5/hr, which is about the average hourly wage of production workers in the Chicago SMSA. Substituting these values of $\hat{W}$ and H into Eq. 20.3 results in the overtime adjustment cost for transportation and utility operations of \$2,556,000 shown in Table 20.5.

It is assumed that large manufacturing firms require one day after an episode to start up operations. Since \$2,577,000 of the overtime cost for manufacturers is from large firms (see Chapter 12), the overtime adjustment cost of Action 18 for an n-day episode is, as indicated in Table 20.1:

$$C' = 25,234,000 \cdot n + 2,577,000 \qquad (20.4)$$

Delay Cost

The delay cost includes both the cost of delaying retail and service consumption and the cost of delaying air freight. The delays of freight shipped by truck and government services are included in the estimate of delays in retail and service consumption. Since it is assumed items are shipped by air to save time, a delay in air freight has a cost that is distinct from consumption delays.

The delay costs are summarized in Table 20.6. The air transportation delay includes delays in the use of air transport services and the delays in

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*In 1972, 214,000 of the 695,000 of non-government trucks registered in Illinois (i.e., 30.8%) were used for personal use [Ref. 3; references are listed in Sec. 20.4].

Table 20.6. Delay Cost of Action 18

Episode Length (days)	Delay Cost ($\$10^3$) Air. Trans. (SIC 45)	Retail Trade (SICs 52-59)	Service (SICs 70-89)	Total
1	134	50.8	18.4	203
2	401	116	42.0	559
3	801	196	70.9	1,070
4	1,310	290	105	1,710
5	2,020	399	144	2,560

air freight. These estimates, obtained from Chapter 21, do not include the cost of detaining passengers away from their homes, a cost that is considered later in this chapter.

The retail trade and service delay costs for an n-day episode are estimated as follows:

$$\underline{C} = \sum_{t=1}^{n} D \cdot P_t = D \cdot \sum_{t=1}^{n} P_t \qquad (20.5)$$

where:

$\underline{C}$ ≡ the consumption delay cost,

D ≡ the average daily sales delayed, and

P_t ≡ the delay factors.

All retail and service activity is assumed to be curtailed. Total retail sales and service receipts in 1972 were $17,231,496,000 [Ref. 1] and $6,234,812,000 [Ref. 2], respectively. The 1974 average daily sales or receipts are therefore D (retail) = $55,649,279, and D (service) = $20,135, 384.* The values of the delay factors are given in Table 20.7. Substituting either the value of D (retail) or D (service), and the P_t values into Eq. 20.5 results in the delay costs for retail trade and service given in Table 20.6; the total delay costs in Table 20.6 are repeated in Table 20.1.

Spoilage Cost

It is possible that during an episode some products may spoil. No data are available on spoilage; however, it is reasonable to conclude that with

*See Table A.6 for consumer price indices.

Table 20.7. Assumed Minimum and Maximum Delays and Corresponding Delay Factors

t	Minimum Delay (days)	Maximum Delay (days)	Delay Factor[a] P_t
1	1	8	0.000913
2	2	9	0.001174
3	3	10	0.001435
4	4	11	0.001695
5	5	12	0.001956

[a]A 10% discount rate is assumed; see Table A.7 and discussion in Sec. 2.1.

refrigeration, short delays in production and sales will result in little spoilage of perishable goods. Since there is the likelihood of some spoilage, it is assumed that one percent of the value of food products sold each day might spoil.

In 1972, $\$3,318 \cdot 10^6$ worth of food was sold in the Chicago SMSA [Ref. 1], or $10,715,500/day worth in 1974 dollars.* Therefore, the estimated spoilage cost is $107,155/day, as shown in Table 20.1.

Landfill Cost

The landfill costs in Table 20.1 are the sum of the landfill costs for municipal/commercial and small incinerators given in Table 19.1. Inclusion of landfill costs for the small incinerators may result in an overestimate of the landfill costs, since the small incinerators may stockpile waste for later incineration rather than landfill it. Furthermore, incineration of waste is not directly prohibited by Action 18. Therefore, if the person doing the incineration is not affected by Action 18 (e.g., the person may live at incinerator site) there would be no landfill cost for small incinerators. Since the inclusion of the costs to small incinerators can only result in a small overestimate of the total cost of Action 18, no refinement in the estimate is made.

Cost of Diverting Through Traffic

One impact of Action 18 is to divert through traffic around the affected area. The cost of diverting people traveling by air is $141,552/day, as estimated in Chapter 21. The daily cost of diverting trucks and cars is estimated as follows:

$$\tilde{C} = \sum_{j=1}^{2} (\tilde{V}_j \cdot P \cdot M_j + N_j \cdot T_j \cdot H) \qquad (20.6)$$

*See Table A.6 for consumer price indices.

where:

$\tilde{C}$ ≡ the cost of diverting through traffic;

j ≡ vehicle type: 1 = cars and 2 = trucks;

$\tilde{V}_j$ ≡ the vehicle miles traveled per day in the study area by through traffic of vehicle type j;

P ≡ the fractional increase in vehicle miles traveled by through traffic if it is diverted;

M_j ≡ the cost per mile of using vehicle type j;

N_j ≡ the number of persons making through trips in vehicle type j;

T_j ≡ the value of time or wage rate of persons traveling in vehicle type j, and

H ≡ the increased travel time caused by diverting traffic.

The vehicle miles traveled per day by through-traffic automobiles and trucks in the six-county Chicago SMSA and Lake and Porter counties in Indiana are 1,907,178 [Ref. 9] and 626,920 [Ref. 7], respectively. Approximately 92.4% of the internal truck trips occur in the six-county Chicago SMSA [Ref. 8]. Assuming this percentage is applicable to all through traffic, then $\tilde{V}_1$ = 1,762,232 miles/day and $\tilde{V}_2$ = 579,274 miles/day.

The fractional increase in vehicle miles traveled caused by diverting through traffic, P, is estimated by calculating the airline distance around and through the study area. Traveling in a north-south direction, the difference in these distances is 185-95 = 90 miles. The fractional increase in the travel distance is P = (185-95)/95 = 0.947; this is assumed appropriate for trips in all directions.

The value of M_1 is assumed to be \$0.13/mile, which is the tax allowance for operating an automobile provided by the IRS of \$0.15 adjusted to 1974 dollars. The value of M_2 is assumed to be $\$0.13 \cdot (13.6/7.21) = \$0.245$/mile. The factors 13.6 and 7.21 are the average miles per gallon for automobiles and trucks, respectively (see Table 18.2).

In the eight-county Chicago-Gary area, 52,600 through automobile [Ref. 9] and 8,290 through truck [Ref. 8] trips are made daily; in the Chicago SMSA, the number of through trips is estimated to be 0.924 • 52,600 = 48,602 and 0.924 • 8,290 = 7,660, respectively. The average occupancy for all types of trips made by automobile is 1.46 persons.* Therefore, N_1 = 1.46 • 48,602 =

*Estimated from data supplied by the Chicago Area Transportation Study [Ref. 7].

70,959 persons. Assuming that there is only the driver in each truck, then $N_2 = 7{,}660$.

The values of T_1 is set equal to \$2.50 [Ref. 10] and T_2 is set equal to \$5.00, which is approximately the hourly wage of production workers in the Chicago SMSA. This wage is assumed appropriate for truck drivers.

The value of H is calculated by assuming that through trips are usually made on expressways during off-peak periods. Therefore, vehicles travel at an average speed of 49.9 mph (see Appendix E). If diverted, they are assumed to use rural roads and travel at an assumed speed of 40.0 mph. Therefore, $H = 185/40.0 - 95/49.9 = 2.72$ hrs.

Substituting the values of $\tilde{V}_j$, P, M_j, N_j, T_j and H into Eq. 20.6 results in a daily cost of diverting through traffic of: $\tilde{C} = \$699{,}470 + \$238{,}576 = \$938{,}046$, where the cost of diverting automobiles is \$699,470/day and of diverting trucks, \$238,576/day. Adding these costs to the cost of diverting airline passengers results in the diversion of through traffic costs in Table 20.1.

Cost of Canceled Trips

It is possible that some trips to and from the Chicago SMSA will be canceled if travel to and from the area is restricted. The cost of canceled trips by persons traveling by air is estimated to be \$570,616/day in Chapter 21. Because of the lack of information available to determine the number and type of automobile, bus, and train trips that might be canceled, it is assumed that the cost of canceled trips is twice the cost for air travelers, i.e., \$1,141,232/day, as shown in Table 20.1.

Detainment Cost

Restricting travel may result in some people being detained away from their homes. For an n-day episode this cost is:

$$C'' = G \cdot \sum_{t=1}^{n} t \qquad (20.7)$$

where:

C'' ≡ the detainment cost,

G ≡ the daily cost of detaining people away from home, and

The summation factor is the number of cumulative days that persons will be detained from home if an episode lasts n days.

For persons traveling by air, the daily cost of detaining them away from home is assumed to be \$202,260. For lack of any information, it is assumed that G is twice this value for all persons detained away from home due to Action 18. Substituting G = \$404,520 in Eq. 20.7 results in the detainment costs given in Table 20.1.

Special Issues

A number of cost components calculated in other actions are not included here because they are no longer relevant or do not apply to Action 18. The most important of these is the cost of changing power plant operations and reducing electricity demand. These costs are not applicable to Action 18, since the restriction of motor vehicle traffic alone will not require power plants to change operating conditions or require persons or firms to reduce electricity consumption.

However, electricity demand may decrease as a result of Action 18 because many businesses will be closed. This reduced demand does not reflect a real cost of Action 18, i.e., lost satisfaction, but only an income redistribution. Although no real cost is incurred, the emission reductions due to reduced electricity demand are included in the emission reduction effectiveness calculation.

The costs of substituting alternative modes of travel or sources of power are no longer relevant since the need for making the substitution is eliminated. For example, substituting mass transit for the automobile to get to work is irrelevant since mass transit vehicles are not operating and most work places are closed.

Similarly, the child care cost that would result if schools are closed is no longer relevant since most or all of the working mothers will also be at home.

20.2 EMISSION REDUCTION EFFECTS OF ACTION 18

Vehicular Sources

The emission reduction due to the restriction on the use of non-essential* motor vehicles is estimated with the following equation:

$$R_p = A_p + B_p + G_p \tag{20.8}$$

where:

R_p ≡ emission reduction of pollutant p due to the action (tons/day);

p ≡ pollutant: 1 = hydrocarbons, and 2 = nitrogen oxides;

A_p ≡ emission reduction due to curtailing traffic; this quantity is equal to total motor vehicle emissions minus emissions from essential vehicles (tons/day);

B_p ≡ emission reduction due to an increase in the average speed of essential vehicles remaining in operation (tons/day); and

G_p ≡ evaporative emission reductions due to reduced sales of gasoline (tons/day).

The variable A_p is defined as follows:

$$A_p = T_p - \sum_{j=1}^{4} \sum_{i=1}^{4} V_i \cdot f_j \cdot E_{pi}(S_j^*)/907{,}184 \tag{20.9}$$

where:

T_p ≡ emissions of pollutant p by all motor vehicles before the action (tons/day);

j ≡ traffic segment: 1 = expressway peak, 2 = expressway off-peak, 3 = arterial peak, and 4 = arterial off-peak;

i ≡ vehicle classes having essential travel: 1 = low-mileage autos (ambulances, emergency utility autos, automobiles of employees of essential services), 2 = high-mileage autos (police cars), 3 = light gasoline trucks (emergency utility trucks), and 4 = heavy gasoline trucks (fire trucks);

V_i ≡ Vmt of essential vehicles in vehicle class i;

f_j ≡ fraction of essential vehicle Vmt occurring during traffic segment j,

$E_{pi}(S_j^*)$ ≡ emission rate of pollutant p for essential vehicles in vehicle class i, at average speed S_j^* (grams/mile); and

The constant 1/907,184 converts grams to tons.

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*Essential refers to police, fire, health service, and utility emergency vehicles and vehicles driven to work by people performing these services.

The variable B_p is defined as follows:

$$B_p = \sum_{j=1}^{4} \sum_{i=1}^{4} V_i \cdot f_j \cdot [E_{pi}(S_j^*) - E_{pi}(S_j')]/907{,}184 \qquad (20.10)$$

where:

$j \equiv$ the four traffic segments; note that, in evaluating speed increase effects for other actions, it was assumed that average speeds during only the peak periods would increase if some traffic was curtailed during these periods. In the case of emergency vehicles, speeds are less constrained by traffic signalization, particularly for ambulances, fire trucks, and police cars. Reducing off-peak traffic, as well as peak traffic, will result in speed increases for essential vehicles;

$E_{pi}(S_j^*) \equiv$ emission rate of pollutant p by essential vehicles in class i and traffic segment j before the action at average speed S_j^* (grams/mile);

$E_{pi}(S_j') \equiv$ emission rate of pollutant p by essential vehicles in class i and traffic segment j after the action at increased speed S_j'; and

i, V_i, f_j, and the constant 1/907,184 are defined as in Eq. 20.9.

The Vmt information on essential vehicle use is shown in Table 20.8.

Table 20.8. Essential Vehicle Usage

Vehicle Class	Estimated Daily Vmt V_i[a] (miles/day)
Low-Annual-Mileage Autos (i = 1)[a]	
Ambulances	14,576[b]
Essential Utility (excl. worker)	1,491[c]
Essential Utility (worker)	200,748
High-Annual-Mileage Autos (i = 2)	
Police Cars	431,724[b]
Light Gasoline Trucks (i = 3)	
Essential Utility	18,100[c]
Heavy Gasoline Trucks (i = 4)	
Fire Trucks	8,020
TOTAL	674,659

[a]Variables in Eqs. 20.9 and 20.10.

[b]Discussed in Appendix E.

[c]Discussed in Chapter 9.

Except for the Vmt data for the employees of essential utility operations (electricity, water, sewage, natural gas, etc.), and fire trucks, the Vmt estimates in Table 20.8 are estimated elsewhere in this report. The Vmt for employees of essential utility services is 0.675% of the total of 29,740,458 work trip Vmt (see Appendix E). The 0.675% figure is the percentage that employment in SIC 49 (electric, gas and sanitary service) is of total employment in the Chicago SMSA in 1973 [Ref. 5]. The fire truck Vmt estimate is twice the average daily truck Vmt figure of 4,010 obtained from the Chicago Fire Department.

For purposes of calculating emissions, the Vmt estimates in Table 20.8 must be apportioned to each traffic segment. For lack of more information, it is assumed that essential traffic other than essential worker trips is distributed evenly throughout all hours of the day rather than being heaviest during the peak hours, as is the case with traffic in general. For example, during the five peak hours, 5/24 of the essential non-worker Vmt occurs. Essential work trip Vmt is assumed to be divided among traffic segments like general work trips are, i.e., 22.0% expressway peak travel, 3.9% expressway off-peak travel, 63% arterial peak travel, and 11.1% arterial off-peak travel. The resulting factors for apportioning essential Vmt among the four traffic segments are shown in Table 20.9.

The average speed of essential vehicles is higher than the average speed of traffic in general. The magnitude of the speed difference is not apparent. Due to this uncertainty, essential vehicle emissions are estimated for three possible cases: (1) they travel at the same average speed as general traffic during each traffic segment, (2) they travel an average of 10 mph

Table 20.9. Essential Vmt Breakdown by Traffic Segment

Traffic Segment	Vmt Fraction, f_j [a]
Expressway Peak	0.103
Expressway Off-Peak	0.156
Arterial Peak	0.296
Arterial Off-Peak	0.445
TOTAL	1.0

[a] Variable in Eqs. 20.9 and 20.10.

faster and (3) they travel at very high speeds (38.3 mph) during all traffic segments. The emission factors for the first case are presented in Tables E.4 and E.5; for the second and third cases the emission factors appear in Tables 20.10 and 20.11.

The emissions of essential vehicles are calculated by combining the data in Tables 20.8 through 20.11 as indicated by Eq. 20.9. Table 20.12 contains the results of these calculations for the three assumptions about vehicle speed. Essential vehicle emissions are almost insignificant relative

Table 20.10. HC Emission Factors

	Case 2[a] Emission Factors (grams/mile)				Case 3[b] Emission Factors (grams/mile) for All Traffic Segments (38.3 mph)
Vehicle Class	Expressway Peak[c] (53.7 mph)[d]	Expressway Off-Peak[c] (59.9 mph)	Arterial Peak (21.9 mph)	Arterial Off-Peak (33.9 mph)	
Low-Mileage Autos	4.36	4.36	6.29	4.95	4.68
High-Mileage Autos	3.94	3.94	5.69	4.47	4.23
Light Gasoline Trucks	6.78	6.78	9.87	7.71	7.29
Heavy Gasoline Trucks	18.72	18.72	28.22	21.61	20.32

[a]"Case 2" assumes essential vehicles travel an average of 10 mph faster than general traffic during each traffic segment.

[b]"Case 3" assumes essential vehicles travel at 38.3 mph during all traffic segments.

[c]Emission factors are assumed to be constant for speeds greater than 49.9 mph.

[d]Average traffic speed for traffic segment.

Table 20.11. NO_x Emission Factors

	Case 2[a] Emission Factors (grams/mile)				Case 3[b] Emission Factors (grams/mile) for All Traffic Segments (38.3 mph)
Vehicle Class	Expressway Peak[c] (53.7 mph)[d]	Expressway Off-Peak[c] (59.9 mph)	Arterial Peak (21.9 mph)	Arterial Off-Peak (33.9 mph)	
Low-Mileage Autos	4.84	4.84	4.00	4.36	4.51
High-Mileage Autos	4.87	4.87	3.99	4.37	4.51
Light Gasoline Trucks	5.93	5.93	4.88	5.33	5.50
Heavy Gasoline Trucks	11.84	11.84	9.90	10.73	11.04

[a]"Case 2" assumes essential vehicles travel an average of 10 mph faster than general traffic during each traffic segment.

[b]"Case 3" assumes essential vehicles travel at 38.3 mph during all traffic segments.

[c]Emission factors are assumed to be constant for speeds greater than 49.9 mph.

[d]Average traffic speed for traffic segment.

Table 20.12. Essential Vehicle Emissions

Assumption	Total Emissions (tons/day) HC	NO_x
1. Essential vehicle speed equals general traffic speed.	4.79	3.21
2. Essential vehicle speed is 10 mph greater than general traffic speed for all traffic segments.	3.84	3.34
3. Essential vehicle speed is very high and equal for all traffic segments.	3.46	3.23

to total vehicle emissions, no matter what assumptions are made about average speed. Assuming the emission estimates from the second case are the most likely, the effectiveness of the action is equal to total vehicle emissions (calculated in Appendix E) minus essential vehicle emissions:

$$\text{HC reduction} = 730.0 - 3.84 = 726.2 \text{ tons/day}$$

$$NO_x \text{ reduction} = 507.3 - 3.34 = 504.0 \text{ tons/day}$$

The additional effect due to the speed increase of essential vehicles can be calculated from Eq. 20.10. It is apparent from Eq. 20.10 that since the Vmt of essential vehicles is so small and emission factors for both HC and NO_x are almost constant at the high speeds of essential vehicles, the change in emissions due to a speed increase is insignificant.

The evaporative hydrocarbon emission reduction from the reduced sales of gasoline, G_1, is estimated in Appendix G to be 47.4 tons/day. The value of G_2 is zero. Thus,

$$R_1 = 726.2 + 47.4 = 774 \text{ tons HC/day, and}$$

$$R_2 = 504 \text{ tons } NO_x\text{/day.}$$

These vehicular source emission reduction effects are shown in Table 20.1.

Stationary Sources

Airport Operations. The emission reductions from curtailed airport activity are estimated to be 18.7 tons of HC and 9.94 tons of NO_x per day (see Table 21.1). The emission reductions from access traffic and vehicle traffic to and from the airport are included in the vehicular source emission reduction estimates.

Electric Power Generation. The demand for electricity will be reduced because of reduced economic activity (e.g., no manufacturing). The average weekend electricity generated was 22.8%, 13.3%, and 25.8% less than the average weekday generation in April, July, and August of 1974 in the Commonwealth Edison System [Ref. 6]. The weighted average percent difference between weekend and weekday electricity generation for these three months is 20.6%. The demand reduction from Action 18 should be slightly greater than experienced between weekdays and weekends because of the greater reduction in economic activity. However, demand reductions will be smaller if the episode occurs during a weekend. It is assumed that the reduction in electricity demand resulting from Action 18 is between 20 and 25%. The daily emission reduction from power plants *without* load and fuel switching for generation reductions of 20% and 25% are 3.952 tons HC and 4.380 tons HC and 186.9 tons NO_x and 235.3 tons NO_x, respectively. These figures are obtained from the Power Plant Simulation Model described in Appendix B. The average values, or 4.416 tons HC and 211.1 tons NO_x, are assumed to be the utility emission reduction effects of Action 18.

Incinerators. The emission reduction effects from restricting incinerator operations are estimated to be 10.8 tons HC/day and 5.57 tons NO_x/day (see Table 19.1). The emission reductions from waste collection vehicles are included in the vehicular source emission reduction estimates.

Manufacturing and Processes. The emission reduction effects from curtailing manufacturing and other emission source processes are estimated to be 640 tons HC/day and 98.5 tons NO_x/day, (see Table 22.1). The emission reductions from curtailing work trips to these establishments are included in the vehicular source emission reduction estimates.

Organic Material Handling. The reduction of HC emissions from the loading and unloading of large gasoline storage tanks is estimated to be 36.0 tons/day (see Chapter 18).

Summary. Table 20.13 summarizes the emission reduction effects of Action 18 for stationary sources. The aggregate emission reduction effects for various length episodes are shown in Table 20.1.

20.3 SENSITIVITY ANALYSIS FOR ACTION 18

Many of the cost components of Action 18 are sensitive to the assumptions made. However, the total cost estimate is relatively insensitive to these assumptions, since the overtime adjustment cost is at least 77.5% of the total cost. Therefore, the most important assumptions are those that relate to the overtime costs.

20.4 REFERENCES

1. *Census of Retail Trade, 1972,* Area Statistics, Illinois, U.S. Department of Commerce, RC72-A-14 (1976).

2. *Census of Selected Service Industries, 1972,* Area Statistics Illinois, U.S. Department of Commerce, SC72-A-14 (1976).

3. *Census of Transportation: Truck Inventory and Use Survey, 1972,* Illinois, U.S. Department of Commerce (1972).

Table 20.13. Daily Emission Reductions from Stationary Sources

Source	Emission Reductions (tons/day)	
	HC	NO_x
Airport Operations	18.7	9.94
Electric Power Generation	4.42	211
Incineration	10.8	5.57
Manufacturing and Processes[a]	640	98.5
Organic Material Handling[b]	36.0	--
TOTAL	710	325

[a]Includes dry cleaners.

[b]Does not include the emissions from the sale of gasoline.

4. *Compilation of Air Pollution Emission Factors*, U.S. Environmental Protection Agency, AP-42 (1975).

5. *County Business Patterns, 1973, Illinois*, U.S. Department of Commerce (1974).

6. Data from Commonwealth Edison Company records.

7. Saricks, C., Chicago Area Transportation Study, personal communications (1976).

8. Warnke, J., and D.A. Zavattero, *Motor Truck Freight in the Chicago Region*, Chicago Area Transportation Study (to be published).

9. Zavattero, D.A., Chicago Area Transportation Study, personal communications (1976).

10. Zerbe, D., and K. Croke, *Environmental Regulations for Urban Transportation*, Ballinger Publishing Co., Cambridge, Mass. (1975).

21 CURTAILMENT OF AIRPLANE DEPARTURES -- ACTION 19

During an emergency all aircraft flights leaving the area of the emergency are forbidden except for reasons of public health or safety. Although aircraft will be allowed to land, airline personnel anticipate that all flights to and from the airport will be canceled to avoid losing the use of grounded aircraft [Refs. 8, 10].* In the analysis of Action 19, it is assumed that all flights into and out of the affected area will be canceled. The costs and emission reductions are calculated only for O'Hare International Airport; although there are numerous small airports in the Chicago area, the size of O'Hare makes the effects of curtailing operations at other airports insignificant. The costs and emission reductions of Action 19 are summarized in Table 21.1.

Table 21.1. Summary of the Costs and Emission Reduction Effects of Curtailing Airplane Departures

Episode Length (days)	Costs ($\$10^3$)							
	Notification	Rescheduling	Shut-Down, Start-up	Passenger Rerouting	Canceled Trips	Delay of Passengers	Delay of Freight	Total
1	80.4	9.04	446	142	571	203	133	1580
2	161	18.1	446	283	1140	610	398	3060
3	241	27.1	446	425	1710	1220	795	4860
4	321	36.1	446	566	2280	2040	1330	7020
5	402	45.2	446	708	2850	3060	1990	9500

Table 21.1 (Cont'd)

Episode Length (days)	HC Emission Reductions (tons)				NO_x Emission Reductions (tons)			
	Airport Oprtns.	Access Traffic	Traffic To, From Airport	Total	Airport Oprtns.	Access Traffic	Traffic To, From Airport	Total
1	18.7	2.07	9.85	30.7	9.94	1.49	9.60	21.0
2	37.5	4.15	19.7	61.3	19.9	2.98	19.2	42.1
3	56.2	6.22	29.6	92.0	29.8	4.47	28.8	63.1
4	74.9	8.29	39.4	123	39.8	5.96	38.4	84.2
5	93.6	10.4	49.3	153	49.7	7.45	48.0	105

*References are listed in Sec. 21.4.

21.1 COSTS OF ACTION 19

The lead time or advance warning given to the airlines will affect the costs of the regulation. If no lead time is given, then the airline has the option of diverting planes already en route to the affected airport or landing the planes and losing their services for the duration of the emergency. If planes are diverted the airlines will most likely have to pay for food and lodging for their passengers, and passengers will be delayed. If a plane is landed, then a multimillion dollar investment would remain idle.

However, if sufficient lead time (four to six hours, for example) is provided to allow all planes en route to land, refuel, embark passengers and freight, and take off, then the above costs could be avoided. For this analysis sufficient lead times are assumed to be provided and the costs of passenger care or idle aircraft are not estimated.

The costs that are calculated are those of notifying passengers of flight cancellations, notifying the general public of emergency actions pertinent to airports, rescheduling aircraft and crews, repositioning aircraft and crews (shut-down/start-up cost), rerouting passengers using the affected airport as a transfer station, canceling trips, delaying consumption of air transportation services and expenditures at final destinations (e.g., vacation expenditures), and delaying freight and freight transport services.

Notification Cost

Passengers delayed because of an ozone emergency must be informed of the cancellation of flights to and from O'Hare. Presumably they will be notified by telephone before they would leave for the airport. (If this were not the case, then an additional round trip to the airport would be required and this cost would have to be estimated and added to the cost of Action 19). An average call is assumed to take two minutes.

These assumptions imply a passenger notification cost of:

$$C = N \cdot (T + W/5040 + \overline{W}/5040) \tag{21.1}$$

where:

$C \equiv$ the notification cost,

$N \equiv$ the number of passengers to be contacted,

$T \equiv$ the cost of a telephone call,

$W \equiv$ the average monthly wage of an airline employee,

$\overline{W} \equiv$ the average monthly wage of the persons receiving the calls, and

The constant 5040 is the number of two-minute time periods in a working month of 21 eight-hour days.

To estimate the passenger notification cost T is set equal to $0.10. An average airline employee earned about $18,000 annually in 1974 [Ref. 2], or $1,500 a month. $\overline{W}$ is assumed to equal $840, which is equivalent to $5/hr. In 1974, 16,405,751 persons boarded planes at O'Hare [Ref. 2], an average of 44,947 passengers daily. Approximately 55% of these passengers use O'Hare only as a transfer point [Refs. 7, 8]. Therefore, 44,947 • 0.45 = 20,226 persons/day depart from O'Hare on trips originating in Chicago and 24,721 persons/day depart who began their trips elsewhere. Assuming the same number of persons end their trips in Chicago that start trips there, then an estimated (2 • 20,266) + 24,721 = 65,173 passengers pass through O'Hare daily. Substituting these data into Eq. 21.1 results in an estimated passenger notification cost of: $C = 65{,}173 \cdot (0.10 + 1500/5040 + 840/5040) = \$36{,}776/\text{day}$.

The airline companies that operate at O'Hare and the airport management are assumed to be notified by telephone of the emergency. Equation 21.1 is also used to estimate this cost. The number of airlines operating at O'Hare is N = 32 [Ref. 5]. Setting W = $1,500, $\overline{W}$ = $1,416 (see Director of Personnel I in Table A.5), and T = $0.10, the resulting cost is $21.71/day.

The public and airport employees are assumed to be informed of curtailed airport activity through radio and TV announcements. Furthermore, friends and relatives of passengers delayed or rerouted will probably be contacted directly by each passenger. The cost of radio and TV announcements is $6,800/day, as estimated in Appendix D. Direct communications between passengers and friends and relatives are assumed to be made by telephone; the cost of these calls would not differ substantially from the passenger notification cost estimated above. For simplicity they are assumed to be the same. Therefore, the total notification cost is twice the passenger notification cost, plus the airline company notification cost, plus the radio and TV cost. The sums of these costs for various length episodes are provided in Table 21.1.

Rescheduling Cost

Both aircraft and flight crews will need to be rescheduled during and after an ozone emergency. Herman Rumsey of Braniff International Airlines estimates that for a one-day shut-down of O'Hare "four man hours would be required to reschedule aircraft for a shut-down and resumption of services and 20 man hours to reschedule flight crews" [Ref. 10]. Using an average annual compensation per airline employee of $18,000 [Ref. 2], the estimated rescheduling cost for Braniff is: [$18,000/(260 • 8)]•24 = $208/day, where 260 is the number of working days per year and eight is the number of hours in a working day.

Braniff had 21 scheduled arrivals and 21 scheduled departures per day in June of 1976 [Ref. 5]. These 42 segments (a segment is either an arrival or departure) represent 2.3% of the 1,816 daily segments [Ref. 5] at O'Hare during the same time period. Assuming the rescheduling cost is proportional to the number of segments, the total rescheduling cost is: $208/0.023 = $9,043/day. The rescheduling costs for various length episodes are presented in Table 21.1.

Shut-Down/Start-Up Cost

During an emergency aircraft and crews that normally would use O'Hare would be diverted to other locations. After the emergency, these aircraft and crews must be repositioned before normal operations can resume. The repositioning may involve flying empty planes or transporting inactive crews. Monte Lazarus of United Airlines estimates a range of repositioning costs of "$50,000 to several hundred thousand dollars" [Ref. 8]. For this analysis United's shut-down and start-up costs are set equal to $100,000.*

United operates about 22.4% of the daily segments at O'Hare [Ref. 5]. Assuming shut-down and start-up costs are proportional to the number of segments operated by each airline implies a total shut-down and start-up cost of: $100,000/0.224 = $446,429. This cost is considered to be independent of the length of the emergency, as indicated in Table 21.1.

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*The average cost of operating an air carrier (including crew, fuel, insurance, and maintenance costs but not depreciation) is estimated to be $800/hr [Ref. 1]. This cost implies an average of about 0.6 hr per scheduled departure of United flights at O'Hare to incur repositioning costs of $100,000.

Cost of Rerouting Through Passengers

Approximately 24,721 passengers/day used O'Hare as a transfer point in 1974. Since Chicago was not the origin or final destination for these passengers, it is assumed that alternative routes that bypass O'Hare or use other modes of transportation would be used, but at an increased cost.

In 1974 airlines received $11,879,177,000 in revenues from 207,449,000 passengers [Ref. 2], which implies an average air transportation cost of $57.26/passenger. Therefore, the daily rerouting cost, $\overline{C}$, is estimated as:

$$\overline{C} = (24{,}721 \cdot 57.26)\cdot\alpha \qquad (21.2)$$

where α is an assumed fractional increase in transportation costs due to rerouting. Setting α equal to 0.10 yields a rerouting cost of $141,552/day, which is used in Table 21.1.

Cost of Canceled Trips

When faced with a day or more delay, some trips may be canceled. When a trip is canceled, the cost is estimated to equal the full value of the trip, including transportation, food, lodging, and entertainment cost. Only the 40,452 passengers beginning or ending their trips in Chicago each day *may* cancel their trips since it is assumed that through passengers complete their trips by taking alternative routes.

To estimate the full value of a trip, both the air transport and final destination expenditures must be calculated. The average per passenger air transportation cost is $57.26, as calculated previously. The final destination cost is estimated from data on expenditures made in Chicago by conventioneers, businessmen, and tourists visiting Chicago in 1972 [Ref. 4]. Total expenditures were about $838.8 million, of which $135 million represented costs of exhibits. Therefore, personal expenditures were $838.8 - $135 = $703.8 million; this money was spent by an estimated 9.9 million visitors, for an average expenditure per visitor of $71.09. Adjusting this to reflect 1974 dollars yields a cost per trip of $83.80.* The daily cancellation cost $\hat{C}$ is therefore:

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*The consumer price indices for 1972 and 1974 are 125.3 and 147.7, respectively (see Appendix A). The factor for converting 1972 dollars to 1974 dollars is 147.7/125.3 = 1.18.

$$\hat{C} = 40{,}452 \cdot (57.26 + 83.80) \cdot \beta \qquad (21.3)$$

where $\beta \equiv$ the fraction of passengers that cancels trips. Setting $\beta = 0.10$ yields a cancellation cost of $570,616/day, as shown in Table 21.1.

Passenger Delay Cost

The passenger delay cost is partially estimated using the consumption delay cost equation for an n-day episode:

$$C' = \sum_{t=1}^{n} D \cdot P_t = D \cdot \sum_{t=1}^{n} P_t \qquad (21.4)$$

where:

$C' \equiv$ the passenger delay cost due to delayed consumption,

$P_t \equiv$ the delay factor, and

$D \equiv$ the value of the delayed expenditures.

In Table 21.2 delay factors for various assumptions of minimum and maximum delays are presented (see Chapter 2 for details).

One expenditure delayed is the cost of the air transportation services. The value of these services is estimated to be:

$$D = 40{,}452 \cdot (1-\beta) \cdot 57.26 \qquad (21.5)$$

where $\beta \equiv$ the fraction of passengers canceling trips. In the previous section β is set equal to 0.10; therefore, the estimated delayed expenditure is $2,084,653/day. Substituting this value of D and the values of the delay factors in Table 21.2 into Eq. 21.4 provides an estimate of the cost of delayed air transportation services. As an example, the air transport delay cost for a two-day emergency is: $2,084,653·(0.000261 + 0.000652) = $1,903.

Table 21.2. Assumed Minimum and Maximum Delays and Corresponding Delay Cost Factors

t	Minimum Delay (days)	Maximum Delay (days)	Delay Factor[a] P_t
1	1	3	0.000261
2	2	5	0.000652
3	3	7	0.001044
4	4	14	0.002086
5	5	14	0.002217

[a] A 10% discount rate is assumed; see Table A.7 and discussion in Sec. 2.1.

Personal expenditures made at the trip destination are also delayed. To

estimate this delay cost a distinction must be made between passengers delayed at their homes and those detained away from their homes. Only those passengers delayed at their homes will postpone trip expenditures. Half of the passengers traveling are expected to be going home, therefore, 40,452/2 = 20,226 persons will be delayed away from home each day. The number of passengers delayed at their homes is $40{,}452 \cdot (1 - \beta) - 20{,}266 = 16{,}181$.* Estimated average delayed expenditures per passenger are $83.80; therefore, total delayed expenditures per day are equal to: $\overline{D} = 16{,}181 \cdot \$83.80 = \$1{,}355{,}951$. Substituting this figure and the delay factors in Table 21.2 into Eq. 21.4 provides estimates of the cost of delaying these expenditures. For example, the cost of delaying personal expenditures for a two-day emergency is estimated to be: $\$1{,}355{,}951 \cdot (0.000261 + 0.000652) = \$1{,}238$.

Persons detained away from home must provide food and lodging for themselves, which may be more expensive than providing these goods at home. Any increase in these expenditures is considered a cost of delaying these passengers. If δ is the differential expense per day paid by each passenger detained away from home, then the total cost for the 20,266 passengers detained each day is:

$$G = 20{,}266 \cdot \delta \tag{21.6}$$

For an n-day episode, the increased expenditures by all persons detained away from home would be:

$$C'' = \sum_{t=1}^{n} 20{,}266 \cdot \delta \cdot t = 20{,}266 \cdot \delta \cdot \sum_{t=1}^{n} t = G \cdot \sum_{t=1}^{n} t \tag{21.7}$$

Setting $\delta = \$10$ results in an estimate of these costs for a two-day episode of: $\$20{,}226 \cdot 10 \cdot (1 + 2) = \$606{,}780$.

The sum of the delayed expenditure costs for air transportation services and personal expenditures, and the additional expenditures required by passengers away from home, is equal to the total estimated cost of delaying passengers. For example, the passenger delay cost of a two-day emergency is estimated to be 1,903 + 1,238 + 606,780 = $609,921. The estimated values of passenger delay costs for emergencies of different lengths are provided in Table 21.1.

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*Only persons traveling away from their homes would cancel their trips. The value of β is 0.10.

Freight Delay Cost

To calculate the cost of delaying freight it is assumed that the primary reason for shipping a product by air is to save time. Therefore, the difference in the cost of shipping a product by air and an alternative mode of shipment (in \$/ton-mile) divided by the expected time savings (in days) is the value of a day's delay per ton-mile of shipments. Therefore, the delay cost for one day's delay is:

$$Q = (A/365)\cdot(B/\lambda) \tag{21.8}$$

where:

$Q \equiv$ the freight delay cost,

$A \equiv$ the annual ton-miles of freight allocated to O'Hare,

$B \equiv$ the differential freight rate (\$/ton-mile), and

$\lambda \equiv$ the days saved by shipping by air.

In 1974, about 6.1 billion ton-miles of freight, mail, and express shipments were made by air.* Approximately 2.4 billion tons of freight were enplaned at "large hub airports" in the U.S. The number of passengers enplaned at these airports is 64% of the total passenger enplanements nationally. Assuming this percentage also pertains to freight results in a total estimate of freight enplanements in 1974 of 2.4/0.64 = 3.75 billion tons. Three hundred and sixty-seven million tons, or 9.79%, of the national freight enplanement can be attributed to O'Hare. Therefore, the ton-miles of freight allocated to O'Hare is estimated to be $A = (6.1 \cdot 10^9)\cdot 0.0979 = 597 \cdot 10^6$ ton-miles/year.

The average revenue per ton-mile for air freight is \$0.2487 and for truck (class 1) freight is \$0.0866 [Ref. 2]. Therefore, $B = (0.2487 - 0.0866)$ = \$0.1621/ton-mile. If λ is set equal to 2, then $Q = [(597 \cdot 10^6)/365] \cdot 0.1621/2$ = \$132,567/day.

Equation 21.7 is used to estimate the total cost of delaying freight by substituting Q for G. For example, the cost of delaying freight for a two-day emergency is estimated to be: \$132,567$\cdot$(1 + 2) = \$397,701. The costs of delaying freight for various length episodes are provided in Table 21.1.

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*All the data in this paragraph are from Ref. 2.

21.2 EMISSION REDUCTION EFFECTS OF ACTION 19

The procedure used to estimate the effectiveness of Action 19 is based on a methodology developed by Rote et al. [Ref. 9] for assessing the environmental impacts of airports. The emission reduction due to the action is calculated as:

$$R_p = A_p + A'_p + B_p + B'_p + G_p \tag{21.9}$$

where:

- R_p ≡ emission reduction of pollutant p resulting directly and indirectly from curtialing flights at O'Hare (tons/day);
- p ≡ pollutant: 1 = hydrocarbons, and 2 = nitrogen oxides;
- A_p ≡ aircraft emissions of pollutant p (tons/day);
- A'_p ≡ emissions from aircraft service vehicles at all passenger ramps, cargo ramps, and intra-airport service roads (tons/day);
- B_p ≡ emissions from gasoline and aircraft fuel handling activities (this emission source applies only in the case of hydrocarbons) (tons/day);
- B'_p ≡ emissions of pollutant p from airport access motor vehicle traffic such as buses, taxis, trucks, and passenger cars shuttling passengers and cargo to the airport (tons/day); and
- G_p ≡ emission reduction from reduced sales of gasoline due to reduced vehicle travel (tons/day).

Aircraft emissions are estimated from the following equation:

$$A_p = \sum_{a=1}^{12} \sum_{b=1}^{6} N_{ab} \cdot G_a \cdot T_{ab} \cdot E_{abp} / 2000 \tag{21.10}$$

where:

- a ≡ types of aircraft (B707, DC8, B727, DC9, etc.);
- b ≡ airplane operations: 1 = taxiing, 2 = idling, 3 = landing, 4 = takeoff, 5 = approach, and 6 = climbout;
- N_{ab} ≡ number of aircraft per day of type a which go through operation b;
- G_a ≡ number of engines per aircraft of type a;
- T_{ab} ≡ average time spent by an aircraft of type a in operation b (min.);
- E_{abp} ≡ emission rate of engines of aircraft type a, of pollutant p during operation b (lbs/engine/min.); and

The factor 1/2000 converts pounds to tons.

Service vehicle emissions are estimated by:

$$A'_p = \sum_{v=1}^{17} O_v \cdot U_v \cdot E_{vp}/2000 \qquad (21.11)$$

where:

$v \equiv$ service vehicles: e.g., tractors, belt loaders, container loaders, food tuucks, etc.;

$O_v \equiv$ total operating time of all service vehicles of type v (hrs/day);

$U_v \equiv$ fuel consumption rate of type v vehicles (gal./hr);

$E_{vp} \equiv$ emission rate of pollutant p by type v vehicles (lbs/gal.); and

The constant 1/2000 converts pounds to tons.

Additional HC emissions due to fuel handling and loading are estimated from:

$$B_p = (U \cdot E_x + X \cdot E_e + Y \cdot E_w + Z \cdot E_a)/2000 \qquad (21.12)$$

where:

$U \equiv$ gallons of gasoline loaded into fixed roof storage tanks daily;

$X \equiv$ gallons of gasoline supplied to service vehicles daily;

$Y \equiv$ gallons of aircraft fuel loaded into fixed roof storage tanks daily;

$Z \equiv$ gallons of aircraft fuel loaded into aircraft daily;

E_x, E_e, E_w, $E_a \equiv$ emission rates for gasoline loaded into fixed roof storage tanks and service vehicles, and aircraft fuel loaded into fixed roof storage tanks and aircraft, respectively (lbs HC/gal. loaded); and

The constant 1/2000 converts pounds to tons.

Emissions from airport access motor vehicle traffic are determined from the following equation:

$$B_p = J_p + K_p \qquad (21.13)$$

where:

$J_p \equiv$ total emissions of access vehicles within the airport boundary (tons/day), and

$K_p \equiv$ total emissions of access vehicles on trips to and from the airport (tons/day).

The quantities J_p and K_p are calculated as follows:

$$J_p = \sum_{i=1}^{4} V_i \cdot E_{pi}(S^*)/907{,}184 \tag{21.14}$$

where:

V_i ≡ Vmt of class i access vehicles within the airport area (miles/day);

i ≡ vehicle classes operating at the airport: 1 = low annual mileage autos -- passenger cars, 2 = high annual mileage autos -- taxis and limousines, 3 = heavy gasoline trucks, and 4 = transit buses;

$E_{pi}(S^*)$ ≡ emission factor for vehicles of class i for pollutant p at average speed S* within the airport boundary (grams/mile); and

The constant 1/907,184 converts grams to tons.

and,

$$K_p = \sum_{i=1}^{4} T_i \cdot L_i \cdot E_{pi}(S)/907{,}184 \tag{21.15}$$

where:

T_i ≡ number of trips per day of vehicles in class i to the airport,

L_i ≡ round trip length of vehicles of class i to the airport (miles),

$E_{pi}(S)$ ≡ emission factor for class i vehicles of pollutant p at average speed S (grams/mile), and

i and the constant 1/907,184 are defined as in Eq. 21.14.

Implicit in Eq. 21.15 are the following assumptions:

- Closing the airport results in the complete elimination of travel by the vehicles which would have made trips to the airport. This would not be the case if trucks were rerouted to other activities, or if people who would have traveled to the airport made substitute trips. Thus the second term in Eq. 21.13 should be regarded as an upper bound of emission reduction with zero as the lower bound.
- The vehicle emissions of access traffic are not calculated by traffic segment, as has been done for other transportation actions. This is because the average speed of vehicles making trips to the airport is relatively homogeneous since most trips probably involve a significant amount of expressway driving.

The total daily emissions due to aircraft, service vehicles, fuel handling, and access traffic in the vicinity of O'Hare are estimated in Ref. 9 for 1972 by the procedures described above. These 1972 estimates are scaled up by 5.6% to account for the growth in operations at O'Hare between 1972

and 1974.* The scaled-up estimates are presented in Table 21.3. It is estimated that a total of 41,427 lbs (20.71 tons) of HC and 22,864 lbs (11.43 tons) of NO_x are produced daily by aircraft and related airport activities.

Additional sources of emissions resulting indirectly from the operation of O'Hare are access vehicles traveling to and from the airport. Such vehicles include passenger cars, buses, trucks, taxis, and limousines. Closing the airport may not result in a reduction of these emissions. Trucks normally making trips to O'Hare, for example, may simply be used to deliver goods elsewhere in the area. (For simplicity it is assumed that travel is completely curtailed.)

Table 21.3. O'Hare Airport Emissions

	Total Emissions[a] (lbs/day)	
Emission Sources	HC	NO_x
Aircraft	31,113[b]	18,545[b]
Ground Service Equipment	4,678	1,341
Aircraft Fuel Handling		
Filling Aircraft	685[c]	0
Filling Fixed-Roof Storage Tanks	770[c]	0
Gasoline Handling		
Filling Service Vehicles	105[c]	0
Filling Fixed-Roof Storage Tanks	105[c]	0
Access Traffic in Vicinity of Airport	3,971[b]	2,978[b]
TOTAL	41,427	22,864

[a]Data are from Ref. 9, scaled up by 5.6% to account for increase in airport activity between 1972 and 1974.

[b]Annual data converted to lbs/day by dividing by 365.

[c]All fuel handling emissions are summer, hot weather values.

*In 1972 approximately 329,000 landing-takeoff cycles [Ref. 9] or 329,000 • 2 = 658,000 operations occurred. In 1974 total O'Hare operations (landings and takeoffs) were estimated at 694,674 [Ref. 6] for an overall increase of 5.6%.

To estimate the vehicle emissions from traffic traveling to and from the airport requires data on the number of vehicle trips, vehicle type, and average trip length, as indicated by Eq. 21.15. Data on vehicle trips are presented in Table 21.4. In addition, data obtained from the authors of Ref. 9 indicate that approximately 75.6% of the vehicles in the passenger access and main public parking area (Table 21.4), were passenger cars, 19.6% were taxis and limousines, 3.7% were buses, and 1.1% were trucks. It is assumed that all vehicles in the cargo area and hangar or maintenance area are heavy gas trucks. The last airport area in Table 21.4 is assumed to consist entirely of passenger cars. The breakdown of airport access trips by vehicle type is shown in Table 21.5.

Table 21.4. Daily Airport Access Vehicles Within Boundaries of O'Hare

Airport Area	Approximate No. of Vehicles/Day[a]
Passenger Access and Main Public Parking	46,464
Cargo Facility	9,029
Hangar or Maintenance Area	4,583
Employee and Overflow Public Parking and USAF Facility	13,675
TOTAL	73,751

[a]Data are from Ref. 9, scaled up by 5.6% to account for increase in airport activity between 1972 and 1974.

Table 21.5. Estimated Trips to O'Hare by Type of Vehicle

Vehicle Class	Trips/day (T_i in Eq. 21.15)
Low Annual Mileage Autos: Passenger Autos	48,802
High Annual Mileage Autos: Taxis and Limousines	9,107
Heavy Gas Trucks	14,123
Transit Buses	1,719
TOTAL	73,751

Average trip length for passenger autos making trips to O'Hare is determined by calculating the distance from the center of the six SMSA counties, and weighting this data by the population of each county. An estimate of 10.9 miles/trip is obtained; this average trip length figure is assumed to hold for taxis and limousines as well. For trucks, the assumption is made that O'Hare trip lengths are equal to the average regional trip length figure of 6.5 miles for trucks in the CATS medium truck category.* The trip data in Table 21.5 are multiplied by the above average trip length estimates to determine daily Vmt of the access traffic; the results are shown in Table 21.6.

It is assumed that all of this access traffic travels primarily on expressways at relatively high speeds. The proportion occuring during peak and off-peak hours is not readily apparent; therefore, two emissions estimates will be made, one assuming 100% peak hour travel and the other assuming 0% peak hour travel. Access traffic emissions are then estimated by applying the emission factors of Tables E.4 and E.5 to the Vmt data of Table 21.6, as indicated by Eq. 21.15.** The emissions, assuming the traffic travels at an average speed of 43.7 mph are: 8,695,886/907,184 = 9.59 tons HC/day, and

Table 21.6. Estimated Vmt Due to Access Traffic Traveling to O'Hare

Vehicle Class	Vmt/Day ($T_i \cdot L_i$ in Eq. 21.15)
Low Annual Mileage Autos: Passenger Autos	503,733
High Annual Mileage Autos: Taxis and Limousines	94,002
Heavy Gasoline Trucks	86,931
Transit Buses	17,745
TOTAL	702,411

*Based on Ref. 11.

**Assuming heavy gasoline truck emission factors apply to the truck Vmt and that transit bus emission factors apply to the bus Vmt.

8,548,587/907,184 = 9.42 tons NO_x/day. Alternatively, assuming an average speed of 49.9 mph, the emissions are: 8,463,578/907,184 = 9.33 tons HC/day, and 8,859,932/907,184 = 9.77 tons NO_x/day.

It is concluded that HC emissions of access traffic total between 9.33 and 9.59 tons/day, and NO_x emissions are between 9.42 and 9.77 tons/day, depending on the average speed of this traffic. The two averages, i.e., 9.46 tons HC and 9.60 tons NO_x, are used.

The evaporative hydrocarbon emission reduction due to reduced sales of gasoline is estimated in Appendix G to be 0.484 ton/day, i.e., $G_1 = 0.484$. The access traffic accounts for 0.083 tons/day and vehicle traffic to and from the airport for 0.401 ton/day of the evaporative hydrocarbon emission reduction. The value of G_2 is equal to zero.

The total effectiveness of the action is equal to the sum of the emissions reductions at the airport, the emissions reduction from reduced traffic traveling to and from the airport, and the reduced evaporative hydrocarbon emissions:

$R_1 = 20.71 + 9.46 + 0.484 = 30.7$ tons HC/day, and
$R_2 = 11.43 + 9.60 = 21.0$ tons NO_x/day.

These emission reductions are shown in Table 21.1.

21.3 SENSITIVITY ANALYSIS FOR ACTION 19

A number of cost estimates are functions of variables for which little or no information is available. The sensitivities of these cost estimates to the assumed values of these variables are discussed below.

Sensitivity Analysis for Rerouting Cost

The value of α used in Eq. 21.2 to estimate the rerouting cost is purely arbitrary. It is easily seen that the rerouting cost estimate is proportional to α, i.e., doubling α would double the cost estimate. If data should become available which could be used to estimate α, the rerouting cost estimate can easily be modified. However, a doubling or tripling of this cost would not significantly affect the total cost estimate.

Sensitivity Analysis for Cancellation Cost

The cancellation cost is relatively high and is sensitive to the assumed value of β. Although in this analysis β is an arbitrary factor, its value can be bounded with some deductive reasoning. To begin with, passengers en route to their homes will not cancel their trips. Since it is reasonable to presume that on any given day half of the passengers will be returning home, the maximum value for β is 0.5.

However, people planning trips that will last a long time, relative to the potential delay, will probably only delay their trips.* It is also reasonable to assume that not all of the people taking trips of relatively short duration will cancel them. These two likelihoods have the effect of significantly reducing the value of β below 0.5.

A maximum value of β might be 0.3. If this were the case, then the cancellation cost would be tripled. However, β may be less than 0.1, resulting in a reduced estimate of the cancellation cost.

Sensitivity Analysis for Passenger Delay Cost

The assumed value of the percentage of passengers canceling trips, β, is unimportant because the contribution of the delayed expenditure costs to the total passenger delay cost is quite small. However, the assumed value of the differential food and lodging expenditures for people detained away from their homes, i.e., δ, can greatly affect the estimated passenger delay cost.

For persons staying with relatives and friends, it is reasonable to assume that the differential cost is close to zero. For individuals using hotels and restaurants the differential cost could be as high as $20/day. It is assumed that the average for all passengers is $10/day in 1974 dollars. Although the estimated passenger delay cost is not proportional to the assumed value of δ, it is almost proportional because of the small contribution to this cost made by delayed expenditures. Therefore, a doubling of δ would almost double the cost estimate while halving it would almost half the estimate.

*The length of the trip may be shortened, resulting in a reduction of final destination expenses. This effect, however, can be simulated by a reduction in β.

Sensitivity Analysis for Freight Delay Cost

The estimate of the freight delay cost is inversely proportional to the assumed value of the time savings of air shipments over truck shipments, i.e., the value of λ. Freight shipments by air tend to be longer than by truck [Ref. 3]. Therefore, it is reasonable to consider shipping distances averaging between 500 and 1,500 miles. Trips of this length can be made in a few hours of air travel, making same-day deliveries possible. On the other hand, a truck traveling an average speed of 50 mph would require at least 10 to 30 hours, making same-day deliveries virtually impossible. This implies that λ is at least equal to 1. If, however, the truck does not travel continuously to its destination (e.g., the driver stops for food or sleep), the delay would be longer. It was assumed λ was equal to two days. If λ is actually closer to one day, the estimated cost would double. The costs would be halved if λ was actually closer to four days.

Summary

Since the costs of rerouting passengers, canceling trips, delaying freight, and delaying passengers account for about two-thirds of the total cost of a one-day episode, the lack of data for estimating these costs is quite important. However, the likelihood of all of these cost estimates being in error in the same direction is probably small. Therefore, it is felt that the estimates presented are reasonable.

21.4 REFERENCES

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3. *Census of Transportation, 1972,* U.S. Bureau of the Census (1972).

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22 CLOSING MANUFACTURING FIRMS AND OTHER LARGE STATIONARY POLLUTION SOURCES -- ACTION 20

During an emergency, all manufacturing and other facilities with process emission source operations are curtailed to the greatest extent possible, short of injuring people or severly damaging equipment. Because information was not available on the degree to which certain industries can be closed down, it is assumed that each firm affected is completely shut down during an episode. The costs and emission reduction effects of Action 20 are summarized in Table 22.1.

22.1 COSTS OF ACTION 20

The costs of Action 20 include those of (1) notifying the affected facilities and their employees of the emergency, (2) inventory or overtime to avoid lost production, (3) shutting down and starting up operations, (4) rescheduling operations, and (5) spoilage of perishable products. The data, methods, and assumptions used to estimate these costs are discussed below.

Notification Cost

The facilities required to curtail activities under Action 10 are assumed to be informed by telephone of the emergency and the actions required of them. The smaller firms and employees are assumed to be notified by radio and TV announcements.

Assuming each phone call lasts two minutes, the telephone notification costs are:

$$C = N \cdot (T + W/5040 + \overline{W}/5040) \qquad (22.1)$$

where:

$C \equiv$ the telephone notification cost,

$N \equiv$ the number of facilities requiring notification,

$T \equiv$ the cost of a telephone call,

$W \equiv$ the monthly wage rate of the person making the telephone call,

$\overline{W} \equiv$ the monthly wage rate of the person receiving the telephone call, and

The constant 5040 is the number of two-minute time periods in a working month (i.e., in 21 eight-hour days).

Table 22.1. Summary of the Costs and Emission Reduction Effects of Closing Manufacturing Firms and Other Large Stationary Pollution Sources[a]

Episode Length (days)	Costs ($10)						
	Notification	Inventory	Overtime	Shut-Down & Start-up	Rescheduling	Spoilage	Total
1	6.93	0	15,900	2,850	234	57.1	19,000
2	13.7	0	29,200	2,850	454	114	32,600
3	20.5	0	42,600	2,850	675	171	46,200
4	27.3	0	55,900	2,850	895	229	59,900
5	34.1	0	69,200	2,850	1,120	286	73,500

Table 22.1. (Cont'd)

Episode Length (days)	HC Emission Reductions (tons)			NO_x Emission Reductions (tons)		
	Stationary Sources	Motor Vehicles	Total	Stationary Sources	Motor Vehicles	Total
1	640	108	748	98.5	44.5	143
2	1,280	215	1,500	197	89.0	286
3	1,920	323	2,240	296	134	430
4	2,560	430	2,990	394	178	572
5	3,200	538	3,740	493	223	716

[a]Inventory and overtime costs are functions of the expected frequency and duration of an emergency. If Action 20 is used for a yellow or red alert, the inventory and overtime cost estimates will change. The above results are maximum costs of Action 20 for alert stages called at ozone concentrations < 0.5 ppm and are appropriate for all alert stages called at ozone levels $\geq$ 0.5 ppm.

An estimated 196 firms are affected by Action 10 (see Chapter 12), i.e., N = 196. Assuming the telephone calls are made and received by lower level management personnel, $W = \overline{W}$ = \$1,416 (the medium monthly salary of a Director of Personnel I; see Table A.5). Setting T = \$0.10 and substituting the above values of N, W, and $\overline{W}$ into Eq. 22.1 results in telephone notification costs of \$129.70.

The costs of the radio and TV announcements are \$6,800/day, as calculated in Appendix D. Assuming the telephone calls are only required on the first day of the episode, the total notification cost for an n-day episode is estimated as in Eq. 22.2; notification costs for emergencies of various lengths are provided in Table 22.1.

$$\bar{C} = 6800 \cdot n + 129.7 \tag{22.2}$$

Inventory and Overtime Cost

It is assumed that, whenever possible, firms adjust operations to avoid production losses due to an episode. This may be done either by increasing inventories *prior* to the episode season or using overtime labor *after* an episode; either adjustment will assure that total production will not be affected by an episode. However, the natures of these adjustments are quite different. The inventory adjustment results in a cost whether an episode occurs or not, because inventories would be increased before an episode occurs. On the other hand, the overtime adjustment results in a cost only if an episode occurs. This distinction is quite important, as will be seen later in this section.

The costs of inventory adjustment are the capital finance charge associated with holding the additional inventory and the cost of storing and retrieving the additional inventories. It is assumed that sufficient storage capacity exists and no capital costs will be required for constructing additional storage facilities. These assumptions imply an inventory cost of:

$$\hat{C}(d) = \sum_{j \varepsilon J} \{[d \cdot U_j/365] \cdot [(1 + i)^{\hat{T}} - 1] + W_j \cdot d \cdot \alpha\} \tag{22.3}$$

where:

- $\hat{C}$ ≡ the increased inventory cost,
- j ≡ Standard Industrial Classification (SIC),
- J ≡ the set of industries that uses the inventory option,
- d ≡ the number of lost production days made up using the inventory option,
- U_j ≡ the annual value of production in industry j,
- i ≡ the daily cost of capital,
- $\hat{T}$ ≡ the number of days the extra inventory is held,

$W_j \equiv$ the daily wage rate of individuals in industry j who store and retrieve inventories,

$\alpha \equiv$ the number of man-days required to store and retrieve additional inventories equal to one day's production, and

The constant 1/365 converts the annual value of production to the average daily value of production.

The first term in Eq. 22.3 is the capital finance charge of holding additional inventories of $d \cdot U_j/365$ dollars; the second term, $W_j \cdot d \cdot \alpha$, is the storage and retrieval cost.

The overtime cost is estimated as:

$$\tilde{C}(\bar{d}) = \sum_{j \varepsilon \bar{J}} 0.5 \cdot \bar{W}_j \cdot 8 \cdot P_j \cdot \bar{d} \tag{22.4}$$

where:

$\tilde{C}(\bar{d}) \equiv$ the overtime cost as a function of $\bar{d}$,

$\bar{d} \equiv$ the number of production days made up using the overtime option,

$\bar{J} \equiv$ the set of industries using the overtime option,

$\bar{W}_j \equiv$ the average hourly wage rate of production workers in industry j,

$P_j \equiv$ the number of production workers in industry j,

The constant 0.5 reflects the assumption that, on the average, the overtime rate for production workers is 1.5 times the normal wage rate, and

The constant 8 is the number of hours in a working day.

The first step in estimating inventory and overtime costs is to determine which industries will use each option, i.e., the sets J and $\bar{J}$. Some industries have production or inventory constraints which preclude them from using the inventory option; these constraints are:

- The product is perishable or cannot be inventoried,
- The product is produced to order and cannot be made until a customer orders it,
- A product is dated (e.g., a newspaper) and cannot be inventoried, or
- Production workers already are working more than 40 hours a week and overtime labor would be required to produce additional inventories. In this case, it will always be cheaper to use the overtime option.

Nine industries have been identified that fall into one or more of these categories; by SIC code, they are those that manufacture meat products (201),

dairy products (202), newspapers (271), periodicals (272), commercial printing products (275), petroleum and coal products (29), primary metals (33), and fabricated metals (34); and non-manufacturing facilities such as dry cleaners (721).

The goods produced by industries 201 and 202 are perishable and many non-manufacturing industries affected by the action cannot inventory their outputs. Newspapers and periodicals cannot be inventoried because they are dated. Since the output of commercial printers cannot be separated into the value of items that can be inventoried, it is assumed that all the output is made to order and cannot be inventoried. The SICs 29, 33, and 34 are reported to have had average work weeks per production worker of more than 40 hours for both 1972 [Ref. 5]* and 1973.** For these industries, overtime labor would be required to make up for lost production due to an episode; Table 22.2 shows the wages ($\overline{W}_j$) and number of production workers (P_j) in the Chicago SMSA in such industries, and the overtime costs for a one day's lost production, i.e., for $\overline{d}_{.} = 1$.

For all other industries the inventory or overtime option can be used, with the choice depending on the relative costs of the two options. If an episode occurs, the inventory option will usually be cheaper than the overtime option. However, inventories must be built up in advance of the episode season. If an episode does not occur during a given year or the duration of an episode is less than expected, then inventory costs may be greater than overtime costs. For this reason, each firm would select an inventory/overtime strategy based on the cost of holding inventories and the expected frequency and duration of an emergency.

Good estimates of the frequency and duration of an emergency are not available. However, the Illinois EPA has made some preliminary estimates [Ref. 3]. It is estimated that the expected frequency of ozone concentrations in the Chicago area reaching 0.50 ppm, i.e., emergency levels, is once every 18 years or 0.0556 times a year. The length of time during which meteorological conditions could be such that an emergency *could* occur is estimated to be, at most, one day [Ref. 3]. Assuming that the likelihood of a one- to five-day

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*References are listed in Sec. 22.4.

**The 1973 average weekly hours worked were calculated from the number of production workers and number of production worker man-hours reported in Ref. 1.

Table 22.2 Average Wages and Number of Production Workers in Chicago SMSA in 1974 in Industries with Production or Inventory Constraints and Resulting Overtime Costs

SIC	Avg. Wages ($/hr)[a]	Total SMSA Emplmnt.[b]	% Prod. Workers[c]	% Emplmnt. in Firms with Prod./Inv. Constraints[d]	No. Prod. Workers in Firms with Prod./Inv. Constraints	Overtime Cost for One Day ($)
20	5.07	71,803	70.7	23.3	11,844	240,196
27	6.19	86,240	61.4	70.3	37,214	921,419
29	5.85	6,302	69.4	100.0	4,374	102,352
33	5.98	60,385	81.0	100.0	48,912	1,169,975
34	5.13	118,345	78.2	100.0	92,546	1,899,044
721	3.00[e]	22,847	99.4	100.0	22,700[f]	272,400
TOTAL	5.39	365,922	74.4[g]	78.0[g]	217,590	4,605,386

[a]*Annual Survey of Manufactures: 1973,* U.S. Department of Commerce, M73(A)-6 (1976). Data adjusted to 1974 based on consumer price index; see Table A.6.

[b]See Table A.3.

[c]Based on Illinois data in *Annual Survey of Manufactures: 1973,* U.S. Department of Commerce, M73(A)-6 (1976).

[d]Estimate.

[e]Estimate; see Sec. 24.1.

[f]*County Business Patterns, Illinois, 1973,* U.S. Department of Commerce (1974). Data adjusted to 1974; see Sec. 24.1.

[g]Average.

episode is proportional to the likelihood of meteorological conditions that could result in an emergency, then the likelihood of a one-day emergency is 0.0556, and a longer emergency is virtually impossible.

To determine the inventory/overtime strategy, a firm will solve the following equation for d, i.e., the level of increased inventories:

$$\min \quad \hat{C}(d) + \sum_{n=1}^{5} \tilde{C}(\bar{d}) \cdot L_n \tag{22.5}$$

$$\text{s.t.} \quad \bar{d} = n + 1 - d$$

$$\bar{d} \geq 0, \text{ if } \bar{d} < 0 \text{ set } \bar{d} = 0$$

$$d \geq 0$$

where:

$\hat{C}(d) \equiv$ the cost of increasing inventories by d days of production,

$\tilde{C}(\bar{d}) \equiv$ the cost of overtime labor for $\bar{d}$ days, and

$L_n \equiv$ the likelihood over a one-year period of an emergency lasting n days.

The constraint that $\bar{d} = n + 1 - d \geq 0$ assumes that additional inventories will be depleted before overtime labor is used if an episode occurs.

Before the optimal values of d can be estimated, the inventory cost as determined by Eq. 22.3 must be estimated. To estimate this cost, i, the daily cost of capital, is set equal to $2.611 \cdot 10^{-4}$, which is equivalent to an annual cost of capital of 10%. Since the ozone season lasts from April to September, $\hat{T} = 182$ days, i.e., half a year. Furthermore, it is assumed that two man-days ($= \alpha$) are required to store and retrieve a day's worth of production stored in inventory. Assuming W_j = \$40/day (\$5/hr), Eq. 22.3 becomes:

$$\begin{aligned} \hat{C}(d) &= d \cdot \sum_{j \varepsilon J} (1.3332 \cdot 10^{-4} \cdot U_j + 80) \\ &= d \cdot [1.3332 \cdot 10^{-4} \cdot \sum_{j \varepsilon J} U_j + 8548 \cdot 80] \end{aligned} \qquad (22.6)$$

The variable U_j is set equal to the annual value added by manufacturing in industry j. The set J includes all firms affected by Action 20 that do not have inventory or production constraints that preclude them from using the inventory option; the constant 8,548 reflects the fact that there are 8,548 such firms.

The value added by manufacturing in 1974 in the Chicago SMSA is $\$19,877.6 \cdot 10^6$ (see Table C.2). To obtain the sum of the value added in the affected firms that can use the inventory adjustment option, the proportion of the value added attributed to those firms that are assumed to have inventory or production constraints must be subtracted from the total value added figure. From the Illinois employment data in Ref. 1, approximately 23.3% of the food and kindred (SIC 20) industry and 70.3% of the printing (SIC 27) industry cannot use the inventory option. Applying these percentages for SIC 20 and 27, and assuming that none of the output from SICs 29, 33, and 34 can be inventoried, then the value added for the firms that can use the inventory option is: $\$13,981.1 \cdot 10^6 = [19,877.6 - (0.233 \cdot 2,085.6) - (0.703 \cdot 1,952.2) - 382.9 - 1,329.2 - 2,326.1] \cdot 10^6$.

Substituting the value of $\sum_j U_j$ into Eq. 22.6 results in:

$$\hat{C}(d) = (1,863,960 + 683,840)\cdot d = \$2,547,800\cdot d \qquad (22.7)$$

Using the estimated average hourly wage rates for production workers and estimating the number of production workers in the firms affected by Action 20* as shown in Table 22.3 the overtime cost is estimated to be, from Eq. 22.4:

$$\tilde{C}(\bar{d}) = \$8,716,210\ \bar{d} \qquad (22.8)$$

Equations 22.7 and 22.8 are used in Eq. 22.5 to obtain the best value of d on an aggregated basis. It is assumed that this value is optional for all the firms in J. Recall that it was estimated that $L_1 = 0.0556$, and $L_n = 0$ for n = 2 to 5. Substituting Eqs. 22.7 and 22.8 and these values of L_n into Eq. 22.5 results in the values of $\hat{C}(d)$ presented in Table 22.4.

As indicated in Table 22.4, no inventorying would be used. This conclusion is also reached if large polluting industries affected by Action 10 are assumed to use the overtime option and only the small firms without production or inventory constraints are tested to see if the expected inventory cost is less than the expected overtime cost. Furthermore, if the expected days lost due to an episode is n rather than n + 1 the overtime adjustment is still cheaper.

It is assumed that the larger firms (i.e., those affected by Action 10) require an additional day after the emergency ends to start up operations, i.e., $\bar{d} = n + 1$. For the smaller firms it is assumed no additional time is required, i.e., $\bar{d} = n$. The daily overtime cost for the larger firms is estimated to be \$2,577,000 (see Chapter 12). The daily overtime cost for all firms affected by Action 20 is \$8,716,000 + \$4,605,000 = \$13,321,000 (see Tables 22.2 and 22.3). The overtime cost to the smaller firms is \$13,321,000 - \$2,577,000 = \$10,744,000. Therefore, the overtime adjustment cost for an n-day episode is:

$$\begin{aligned}\tilde{C}' &= 10,744,000\cdot n + 2,577,000\cdot(n + 1)\\ &= 13,321,000\cdot n + 2,577,000 \qquad (22.9)\end{aligned}$$

The inventory cost is, of course zero. The values of $\tilde{C}'$ for various lengths episodes are provided in Table 22.1.

*The firms that have inventory production constraints are excluded to avoid double counting.

Table 22.3. Average Wages and Number of Production Workers in Chicago SMSA in 1974 in Industries without Production or Inventory Constraints and Resulting Overtime Costs

SIC	Average Wages, W_j ($/hr) 1973[a]	Average Wages, W_j ($/hr) 1974[b]	Employment in Industries without Constraints: No. of Employees[c]	% Prod. Workers[d]	No. of Prod. Workers	Overtime Cost for One Day ($\$10^3$)
20	4.57	5.07	55,073[e]	70.7	38,937	789.63
21	4.58	5.08	325	66.3	215	4.38
22	4.58	5.08	3,269	66.3	2,167	44.04
23	3.16	3.51	20,654	82.3	16,998	214.18
24	4.58	5.08	5,800	66.3	3,845	78.14
25	4.58	5.08	16,288	66.3	10,799	219.43
26	4.07	4.52	33,155	76.7	25,430	459.77
27	5.58	6.19	25,613[f]	61.4	15,727	389.39
28	4.54	5.04	41,088	54.2	22,270	448.96
30	3.48	3.86	33,165	80.1	26,565	410.17
31	4.58	5.08	5,524	66.3	3,662	74.42
32	4.43	4.92	22,585	75.9	17,142	337.35
35	5.11	5.67	130,375	70.4	91,784	2,081.66
36	4.19	4.65	134,683	71.4	96,164	1,788.64
37	5.29	5.87	30,542	79.6	24,311	570.83
38	4.58	5.08	29,146	66.3	19,324	392.66
39	3.78	4.19	31,927	77.1	24,616	412.56
TOTAL	4.48[g]	4.96[g]	619,212	71.0[g]	439,956	8,716.21

[a] *Annual Survey of Manufactures: 1973*, U.S. Department of Commerce, M73(A)-6 (1976). For SICs not reported the average wage rate of $4.58/hr reported in the *Annual Survey* for SICs 20-39 is used.

[b] Adjusted based on consumer price index; see Table A.6.

[c] See Table A.3.

[d] Based on data in *Annual Survey of Manufactures: 1973*. For SICs not reported, the average of 66.3% reported in the *Annual Survey* for SICs 20-39 is used.

[e] $71{,}803\cdot(1 - 0.233) = 55{,}073$.

[f] $86{,}240\cdot(1 - 0.703) = 25{,}613$.

[g] Average.

Table 22.4. Optimal Inventory/Overtime Schemes

Additional Days of Inventory	Expected Annual Cost ($\$10^3$)		
	Inventory	Overtime	Total
0[a]	0	969	969
1	2,550	485	3,035
2	5,100	0	5,100
3	7,650	0	7,650
4	10,200	0	10,200
5	12,700	0	12,700
6	15,300	0	15,300

[a]Optimal value of additional days of inventory, d.

Shut-Down and Start-up Cost

Unlike most retail or service businesses, many manufacturing firms cannot simply be closed and left unattended when production is stopped. Furnaces often must be allowed to cool slowly, materials must be stored, security personnel must be kept on duty, etc. The shut-down and start-up procedures most likely vary greatly among firms within industrial groups and among industries. As a result, the costs of shutting down and starting up production processes vary greatly.

Unfortunately, data on these costs are not available. For this analysis, it is assumed that for the larger polluting firms an average of \$2,000 and for smaller firms an average of \$200 is required to shut down and start up operations. Therefore, for the 196 large polluting firms affected by Action 10, and the remaining 12,495 - 196 = 12,299 smaller firms, the shut-down and start-up cost would be: (196 • \$2,000) + (12,299 • \$200) = \$2,851,800. This cost is assumed to be independent of the length of the episode, as indicated in Table 22.1.

Rescheduling Cost

Production schedules must be changed to adjust to an episode. Assuming that an average of one man-day of rescheduling is required per large firm and two man-hours per small firm affected per day lost due to an episode, then the rescheduling cost for an n-day episode is:

$$\underline{C} = N \cdot W/21 \cdot (n + 1) + \overline{N} \cdot W/84 \cdot n$$
$$= (N \cdot W/21 + \overline{N} \cdot W/84) \cdot n + N \cdot W/21$$

where:

$\underline{C} \equiv$ the rescheduling cost,

$N \equiv$ the number of large firms,

$W \equiv$ the monthly wage rate of the person doing the rescheduling,

$\overline{N} \equiv$ the number of smaller firms,

The constant 21 is the number of working days in a month, and

The constant 84 is the number of two-hour periods in a working month.

It is assumed that the number of production days lost is one more than the number of days of the episode.

The value of N is 196 and $\overline{N}$ is 12,299. Assuming lower level management personnel do the rescheduling, then W = 1,416 (see Table A.5, Director of Personnel I medium income). Substituting these values of N, $\overline{N}$, and W into Eq. 22.10 results in the rescheduling cost shown in Table 22.1.

Spoilage Cost

Most manufacturing products are not perishable. However, if production is stopped in food and kindred industries, some products may spoil. There are no data available on spoilage; however, it is reasonable to conclude that with refrigeration, a short delay in production will result in little spoilage of input or final products. Since there is the likelihood of some spoilage, it is assumed that one percent of the value of the food products produced each day might spoil, i.e., the spoilage cost is: $57,140/day = $(2,085.6 \cdot 10^6/365) \cdot 0.01$.* This spoilage cost is shown in Table 22.1.

22.2 EMISSION REDUCTION EFFECTS OF ACTION 20

The effectiveness of Action 20 is estimated using Eq. 22.11. The first term in the equation represents the emission reductions due to facilities curtailing their operations. The annual HC and NO_x emissions of all facilities -- excluding electric utility power plants and incinerators which are covered

*The annual value added in food and kindred industries (SIC 20) affected is $\$2,085.6 \cdot 10^6$; see Table C.2.

by other actions -- emitting more than 25 tons per year of HC, NO_x, sulfur dioxide, particulate matter, or carbon monoxide are summed and divided by 365 to obtain average daily emissions. The emission reduction from curtailing industrial workers' trips to their jobs is represented by the second term and the emission change due to the speed increase resulting from the traffic reduction is calculated with the third term; it is assumed that the only trips curtailed are production employees' work trips and that these individuals make no substitute trips. The last term is the evaporative emission reduction resulting from reduced sales of gasoline.

$$R_p = \sum_f^n E_{fp}/365 + \sum_{j=1}^{4} V_j \cdot E_p^*(S_j)/907{,}184$$
$$+ \sum_{j=1}^{4} \sum_{i=1}^{9} \left\{\overline{V}_{ij} \cdot [\overline{E}_{pi}(S_j) - \overline{E}_{pi}(S_j')]/907{,}184\right\} + G_p \qquad (22.11)$$

where:

R_p ≡ daily emission reduction of pollutant p due to the action (tons/day);

p ≡ pollutant: 1 = hydrocarbons, and 2 = nitrogen oxides;

f ≡ facilities (other than electric utility power plants and incinerators) emitting more than 25 tons per year of any of the five major air pollutants;

E_{fp} ≡ annual emission rate by facility f of pollutant p (tons/year). E_{fp} is divided by 365 to obtain a daily average rate;

j ≡ traffic segment: 1 = expressway peak, 2 = expressway off-peak, 3 = arterial peak, and 4 = arterial off-peak;

V_j ≡ passenger auto Vmt during traffic segment j by production workers driving to and from work (miles/day);

$E_p^*(S_j)$ ≡ emission rate of pollutant p at average speed S_j for passenger autos (grams/mile);

i ≡ vehicle class (see Appendix E);

$\overline{V}_{ij}$ ≡ Vmt of class i vehicles during traffic segment j, after the action (miles/day). The Vmt of all vehicle classes after the action will be the same as before the action except for passenger autos;

$\overline{E}_{pi}(S_j)$ ≡ emission rate of pollutant p by vehicle class i at average speed S_j before the action (grams/mile);

$\overline{E}_{pi}(S_j')$ ≡ emission rate of pollutant p by vehicle class i at average speed S_j' after the action (grams/mile);

G_p ≡ evaporative emission reduction due to reduced average sales of gasoline (tons/day); and

The constant 1/907,184 converts grams to tons.

Only facilities emitting more than 25 tons per year are included in the calculation because this is the extent of the emission data. Because smaller emitters are not included, Eq. 22.11 would tend to underestimate the effectiveness of the action if all facilities were curtailed.

Equation 22.11 assumes that the entire emissions of facilities will be curtailed.. However, as discussed with regard to Action 10, facility emissions cannot be broken down on the basis of incineration, process, and fuel combustion. Since incineration operations would not be curtailed by this action, the use of Eq. 22.11 would tend to overestimate the emission reductions. Also, emission reductions are overestimated because operations that cannot be curtailed due to injuring people or severely damaging equipment are not considered, for lack of information.

In addition, the calculation of daily emissions from dividing yearly emissions by 365 is an approximation method. Since some industries may experience yearly production cycles in which more (or less) activity occurs during the summer months than the rest of the year, the calculated daily emissions would be an underestimate (or overestimate) of the actual amounts. It can be conjectured that facilities producing emissions at a greater rate during the summer months cancel out facilities producing emissions at a lesser rate, and therefore the total average daily emission estimates would be fairly accurate.

An emission inventory obtained from the Illinois EPA [Ref. 2] includes annual emissions for all stationary sources in the Chicago SMSA emitting more than 25 tons per year of any of the five major air pollutants: hydrocarbons, nitrogen oxides, sulfur dioxide, particulate matter, and carbon monoxide.* Electric utility power plants and incinerators were screened from the list. The remaining facilities include manufacturers, dry cleaners, and commercial sources such as office buildings, housing projects, etc. Total emissions from these facilities, estimated using Eq. 22.11, appear in Table 22.5. From Table 22.5, the estimated facility emission reductions are 639.7 tons HC/day and 98.5 tons NO_x/day.

*The emissions inventory was established from data collected in 1971. Since that time, sources have been updated as new information became available. Thus, the inventory consists of data collected between 1971 and 1976, with some estimates probably outdated.

Table 22.5. Stationary Source Emissions for SMSA[a]

Source	Emissions (tons/day) HC	NO_x
Manufacturing and Dry Cleaning	632.7	84.5
Commercial and Other (office buildings, housing projects, hospitals, etc.)	7.0	14.0
TOTAL	639.7	98.5

[a]Includes all sources emitting more than 25 tons per year of any of the five major air pollutants, except for incinerators and electric utility power plants.

Additional emission reductions result when production workers in manufacturing curtail their work trips. As discussed in Appendix E, out of a total passenger auto Vmt of 82,842,500 miles per day, 7.9%, 1.4%, 22.6%, and 4.0% consist of work Vmt during the expressway peak, expressway off-peak, arterial peak, and arterial off-peak traffic segments, respectively. Out of an estimated total of 2,841,659 employees in the SMSA, approximately 627,792 (22.1%) were production workers in manufacturing facilities in 1971. It is assumed that production workers' work trip Vmt is the same percentage of total work Vmt as production workers are of total workers (i.e., f = 0.215 in Eq. 22.11). Thus estimates of work trip Vmt by workers in manufacturing are (V_j in Eq. 22.11):

$$V_1 = 82{,}842{,}500 \cdot 0.079 \cdot 0.221 = 1{,}446{,}347 \text{ miles/day}$$
$$V_2 = 82{,}842{,}500 \cdot 0.140 \cdot 0.221 = 2{,}563{,}147 \text{ miles/day}$$
$$V_3 = 82{,}842{,}500 \cdot 0.266 \cdot 0.221 = 4{,}137{,}652 \text{ miles/day}$$
$$V_4 = 82{,}842{,}500 \cdot 0.040 \cdot 0.221 = 732{,}328 \text{ miles/day}$$

Applying passenger auto emission factors from Tables E.4 and E.5 to the above Vmt estimates, as in Eq. 22.11, the emission reductions due to work trip curtailment are 65.0 tons HC/day and 42.5 tons NO_x/day.

From the Vmt data of Table 22.6 it is estimated that the average speed of arterial peak traffic will increase from 11.9 to 17.5 mph; expressway peak traffic will experience a speed increase from 43.7 mph to 46.6 mph. Emission factors for all vehicle classes were calculated at these new average speeds and Eq. 22.11 was employed to calculate the speed increase effect. The resulting

Table 22.6. Speed Increase Data

Traffic Segment	Vmt before Action (miles/day)	Vmt after Action (miles/day)	Vmt/Hour After Action	Average Speed After Action[a] (mph)
Expressway Peak	7,451,000	6,004,653	1,200,931	46.6
Arterial Peak	21,393,000	17,255,348	3,451,070	17.5

[a]Based on peak speed adjustment equations (Appendix F).

emission reductions from the speed increases are 38.7 tons HC/day and 1.98 tons NO_x/day.

The evaporative hydrocarbon emission reduction, G_1, is estimated in Appendix G to be 4.14 tons/day. The value of G_2 is zero.

The total emission reductions due to the action are estimated at:

$R_1 = 640 + 65.0 + 38.7 + 4.14 = 748$ tons HC/day, and

$R_2 = 98.5 + 42.5 + 1.98 = 143$ tons NO_x/day.

22.3 SENSITIVITY ANALYSIS FOR ACTION 20

The estimated costs of shutting down and starting up operations, rescheduling operations, and spoilage were all estimated with little or no information. However, over 83.7% of the total cost of a one-day episode is due to overtime costs, which were extensively analyzed. Therefore, the lack of information on shut-down/start-up, rescheduling, and spoilage costs has little effect on the estimated total cost of Action 20.

Another area of concern is the fact that the emission inventory used only had facilities that emitted more than 25 tons/year of HC, NO_x, SO_2, CO, or particulate matter. Therefore, emission reductions from very small emission sources were not considered.

Comparing the effectiveness of Action 20 with that of Action 10, it appears that the emissions of small sources do not account for very much of the total HC or NO_x emissions. The emissions of sources producing between 25 and 100 tons per year is the difference between the stationary source emission reductions due to Actions 10 and 20:

HC incremental = 640 - 616 = 24.0 tons/day, and

NO_x incremental = 98.5 - 88.4 = 10.1 tons/day.

Thus, of all facilities producing more than 25 tons per year of HC or NO_x, 96% (616/640) is produced by facilities emitting more than 100 tons of HC or NO_x per year. For NO_x, this figure is 89% (88.4/98.5). Since such a large portion of HC and NO_x emissions is produced by very large facilities, it would seem that the small facilities emitting less than 25 tons per year of both HC and NO_x would not be a significant source of pollution. Ignoring small source emissions in the analysis would not result in significant errors in estimating the action's effectiveness.

22.4 REFERENCES

1. *Annual Survey of Manufactures, 1973,* U.S. Department of Commerce, M73(AS)-6 (1976).

2. Coblenz, J., Illinois Environmental Protection Agency, personal communication (March 31, 1976).

3. Coblenz, J., Illinois Environmental Protection Agency, personal communication (June 9, 1976).

4. *County Business Patterns, 1973: Illinois,* U.S. Department of Commerce (1974).

5. *Employment and Wages in States and Areas: 1939-1974,* U.S. Bureau of Labor Statistics (1975).

6. *Illinois Manufactures Directory,* Manufacturers' News, Inc., Chicago (1974).

23 RESTRICTIONS ON POWER GENERATION AND ELECTRICITY CONSUMPTION -- ACTION 21

During an emergency, electric power generating stations burning fossil fuels are required to reduce emissions in and into the affected area to the greatest extent practicable by adjusting operations system wide, discontinuing power generation for economy sales and service to interruptible customers, and maximizing purchase of available power. In addition, they must effect the maximum feasible reduction of emissions by: reducing voltage 2.5% system wide, purchasing all available emergency power, and requesting large customers (500 kW) to reduce their electric demand, or by any other means approved by the Illinois EPA.

Electric utilities can reduce emissions in the affected area by switching generation to plants outside the area or by using natural gas in plants having a dual fuel capability. Because emission reductions are required, it is assumed that both the load and fuel switching options will be used. Decreased sales and the purchase of power reduce the required amount of electricity to be generated; the reduction in electricity generation is treated parametrically by reducing generation by 0 to 25% of the total expected demand.

Because of the complexity of the options available to power companies, a computer program is used to simulate possible load and fuel switching options. Details of the program, which calculates the costs and emissions of alternative loading patterns and demand schedules, are presented in Appendix B. The resulting costs and emission reduction effects of Action 21 -- assuming both load and fuel switching and a 14.3% reduction in generation from curtailing economy/interruptible sales, requesting large customers to reduce demand, reducing voltage by 2.5%, and purchasing power -- are summarized in Table 23.1 (on the next page).

23.1 COSTS OF ACTION 21

The costs of Action 21 include (1) the cost of notifying the power company of the emergency, (2) increased operating costs resulting from load and fuel switching, and (3) costs associated with reduced electricity generation. The data and assumptions used to estimate these costs are discussed below.

Table 23.1. Summary of the Costs and Emission Reduction Effects of Required Restraints on Electric Power Plant Operations[a]

Episode Length (days)	Costs ($\$10^3$) Notification	Power Plant Oprtn.[b]	Buying Power	Interruptible and Economy Customers	Total	Emission Reductions (tons) HC	NO_x
1	0.496	-380	792	168	580	6.03	227
2	0.993	-759	1580	337	1160	12.1	454
3	1.49	-1140	2380	505	1750	18.1	682
4	1.99	-1520	3170	673	2330	24.1	909
5	2.48	-1900	3960	842	2900	30.2	1140

[a]Assuming both load and fuel switching and a 14.3% reduction in generation.

[b]Includes load and fuel switching costs and operating cost savings from reduced electricity generation.

Notification Cost

The power company is assumed to be notified of an emergency by telephone. Assuming the call lasts two minutes, the notification cost is estimated to be:

$$C = N\cdot(T + W/5040 + \overline{W}/5040) \tag{23.1}$$

where:

$C \equiv$ the notification cost,

$N \equiv$ the number of power plants notified,

$T \equiv$ the cost of a telephone call,

$W \equiv$ the monthly wage rate of the person making the telephone call,

$\overline{W} \equiv$ the monthly wage rate of the person receiving the telephone call, and

The constant 5040 is the number of two-minute time periods in a working month (i.e., in 21 8-hour days).

Since there is only one power company, only one call is required. However, it is possible that each fossil fuel power station will have to be notified. If this occurs, then 12 calls will be made to the power company. Each interruptible/economy and large customer must also be notified of electricity curtailments. There are three interruptible/economy customers. Since 350 MW is the maximum hourly reduction from large customers, a maximum of

350,000/500 = 700 large customers will have to be notified [Ref. 3].* Therefore, N = 12 + 3 + 700 = 715. The value of T is set equal to \$0.10. The telephone calls are assumed to be made and received by lower level management employees; it is assumed that the median monthly income of a Director of Personnel I, \$1,416,** is the average wage rate for all lower level managers in the Chicago SMSA. Therefore, $W = \overline{W}$ = \$1,416.

Substituting these values of N, T, W, and $\overline{W}$ into Eq. 23.1 results in an estimated notification cost of \$496. Notification is assumed to be made each day of the episode. The notification costs for various length episodes are presented in Table 23.1.

Operating Cost

The load and fuel switching costs are estimated by loading fossil fuel power plants outside of the Chicago SMSA before those within the area, and using natural gas to the greatest extent possible in the Chicago SMSA plants. Four steam plants are located outside the Chicago SMSA: Dixon, Kincaid, Powerton, and Sabrooke. In the Chicago SMSA the Waukegan Units 5, 6, 7, and 8; Ridgeland Units 1, 2, 3, and 4; Fisk Unit 19; Crawford Units 6, 7, and 8; and Joliet Units 7 and 8 can switch to natural gas.

Using the standard day with a peak demand of 11,500 MWh, as discussed in Appendix B, the costs of load and fuel switching in each plant, shown in Table 23.2, are calculated. The difference between the cost with and without an episode is the cost (in 1976 dollars) of load and fuel switching assuming no reduction in electricity generation relative to the standard day. This cost in 1974 dollars is \$325,362. Table 23.3 shows the cost of load and fuel switching with reductions in electricity generation of 0, 6, 10, 14.3, 20, and 25%. For electricity generation reductions greater than 6.5% there is an operating cost saving, which is the net effect of increased operating costs due to load and fuel switching and savings due to reduced electricity production.

Economy/interruptible sales are assumed to encompass customers with Rider 17; i.e., the power company can, with short notice, reduce sales to these customers by 50%. The highest historical electric furnace demand recorded by

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*References are listed in Sec. 23.3.

**See Table A.5.

Table 23.2. Estimated Operating Costs for Power Generation with and without Load and Fuel Switching with No Reduction in Electricity Generation

Plant Name and Unit #	Loading Order A[a]	Loading Order B[b]	Operating Costs (1976 $) A	Operating Costs (1976 $) B	Operating Costs (1976 $) Difference (A-B)
Chicago SMSA					
Crawford #6	22	31	4,046	0	4,046
Crawford, #7	21	18	76,161	38,856	40,305
Crawford, #8	12	13	102,507	75,103	27,404
Fisk, #18	32	25	22,620	22,620	0
Fisk, #19	13	15	108,713	62,065	46,648
Joliet, #5	30	23	11,432	11,432	0
Joliet, #6	26	16	35,507	48,863	-13,356
Joliet, #7	15	11	108,359	122,496	-14,137
Joliet, #8	14	10	107,339	126,146	-18,807
Ridgeland, #1	18	29	46,344	0	46,344
Ridgeland, #2	16	30	48,242	0	48,242
Ridgeland, #3	19	27	52,873	0	52,873
Ridgeland, #4	20	28	52,020	0	52,020
State Line, #1	33	26	23,098	23,098	0
State Line, #2	31	24	20,448	20,448	0
State Line, #3	23	9	39,950	45,655	-5,705
State Line, #4	24	12	74,604	80,712	-6,108
Waukegan, #5	17	8	35,653	20,958	14,695
Waukegan, #6	9	7	26,004	14,499	11,505
Waukegan, #7	10	6	64,570	45,303	19,267
Waukegan, #8	11	5	68,784	43,556	25,228
Will County, #1	28	20	27,324	27,324	0
Will County, #2	29	21	27,562	27,562	0
Will County, #3	25	14	50,087	60,218	-10,131
Will County, #4	27	19	90,432	90,432	0
Non-SMSA					
Dixon, #4	6	22	13,189	7,668	5,521
Dixon, #5	5	17	16,177	8,878	7,299
Kincaid, #1	4	4	73,137	73,922	-795
Kincaid, #2	3	3	74,098	76,304	-2,206
Powerton, #5	1	1	113,211	114,443	-1,232
Powerton, #6	2	2	102,710	108,922	-6,212
Sabrooke, #3	8	33	20,437	0	20,437
Sabrooke, #4	7	32	28,256	0	28,256
TOTAL COSTS			1,765,877	1,394,475	371,402

[a]With load and fuel switching. [b]Without load and fuel switching.

Table 23.3. Estimated Cost of Load and Fuel Switching with Simultaneous Reduction in Electricity Generation

Reduction in Electricity Generation[a] (%)	Operating Cost Increase[b] ($)
0	325,362
6	26,333
10	-168,934
14.3[c]	-379,508
20	-633,439
25	-726,881

[a]Based on a typical day output of 241,318 MWh.

[b]Negative numbers imply an operating cost savings.

[c]Obtained by interpolating simulation model results.

customers of Commonwealth Edison with Rider 17 was 442 MW. Therefore, the *maximum* generation reduction would be 221 MW [Ref. 3]. It is assumed that an hourly *average* reduction of 110 MW is possible if sales to these customers are reduced as much as possible. The *maximum* reduction from large customers is 350 MW [Ref. 4]. It is assumed than an hourly *average* reduction of 350/2 = 175 MW from large customers occurs.

"On a day to day basis, neighboring utilities appear able to sell to Edison 500-1000 Megawatts. Some of these companies are contractually bound to sell emergency power for no more than 48 hours for a single set of circumstances" [Ref. 4]. It is assumed that 1,000 MW can be purchased each hour during an emergency. Because of the gravity of the situation, it is assumed that more power can be purchased during an emergency than during a red alert. (It is assumed 500 MW/hr could be purchased during a red alert; see Chapter 13.) The 1,000 MW figure used for an emergency is below the maximum theoretical quantity of electricity that can be purchased in the summer months, i.e., 2,300 MW [Ref. 4]. This figure is not used because it is an extreme value.

A voltage reduction of 2.5% can result in a maximum reduction of 150 MW [Ref. 4]. These data imply that, on the average, about (110 + 175 + 1,000 + 150) = 1,435 MW of electricity generation can be reduced each hour by restricting sales to economy, interruptible, and large customers; buying outside power; and reducing voltage by 2.5%. This is a 14.3% reduction in the expected generation of electricity during a typical episode day. Therefore, a 14.3% reduction in electricity generation is assumed for the power plant operation costs provided in Table 23.1.

Cost of Buying Power

Based on data provided by Commonwealth Edison Company, it is assumed that, on the average, 1,000 MW of power can be purchased each hour, as discussed above. "The range of purchased emergency power has been between 13.5 to 70.0 mills per kilowatt hour. The overall average purchase price has been in the range of 33.0 mills per kilowatt hour" [Ref. 2]. Since this cost is based on historical information, it is assumed appropriate for 1974. The daily cost of purchasing outside power is: $\$729{,}000 = 24 \cdot (1{,}000 \cdot 10^3) \cdot 33 \cdot 10^{-3}$.

Interruptible/Economy and Large Customer Cost

When interruptible and economy sales are curtailed, the customers affected will incur costs to compensate for the lost electricity. These costs may be expenditures made to supply alternative power or to avoid losses in production. Because the names of the customers affected are confidential, it could not be determined how they would cope with electricity curtailments.

The fact that they are on interruptible contracts implies that normal interruptions in electricity service are relatively inexpensive. However, it is not clear that interruptions in service resulting from an episode are similar to those normally experienced. To estimate the costs to these customers, it is assumed that an alternative source of power is available to them in the form of a company-owned peaking unit. (A peaking unit is assumed because the substitute energy would be electricity.) This assumption is based on the fact that many large industrial firms have their own peaking units and it is possible that they also purchase interruptible power. However, no concrete information is available to substantiate this assumption.

The average cost of electricity to the interruptible/economy customers is \$0.0154/kWh [Ref. 3]. The average cost of using peaking units is \$0.0518/kWh [Ref. 1]. The difference of these costs times the amount of electricity produced by the customers' peaking units (110 MW/hr) is the daily cost to these customers of curtailing their electricity service, i.e., $(0.0158 - 0.0154) \cdot (110 \cdot 10^3) \cdot 24 = \$96,096$.

The data obtained from Commonwealth Edison are assumed to be in 1976 dollars. Therefore, this cost in 1974 dollars is: $(147.7/168.6) \cdot 96,096 = \$84,183$/day.*

Large customers, on the other hand, are not subject to service interruptions. However, the curtailment of their sales is voluntary on their part. Therefore, the cost of adjusting to the lost electricity would be small and is assumed equal to the cost to the interruptible/economy customers, i.e., \$84,183/day.

The total cost to interruptible/economy and large customers of electricity service curtailments provided in Table 23.1 is, therefore, $2 \cdot 84,183 = \$168,366$/day.

This cost estimate is quite tenuous because it is based on little or no information. However, during an emergency, it is likely that the interruptible/economy and large customers will also have to curtail their activities because of Actions 18, 20, and 22. If this is true, then the curtailment of electricity sales to them would have little or no cost over and above the cost of these other actions. Therefore, the estimated cost of curtailing sales to interruptible/economy and large customers most likely only affects the relative efficiency of Action 21 and not the cost estimate of an emergency provided later.

Voltage Reduction Cost

The additional cost of reducing voltage by 2.5% is assumed to be minimal. Furthermore, most customers will not perceive any change in their electricity service [Ref. 4]. Therefore, there is no lost satisfaction. The power company may lose revenues because of the voltage reduction but this lost revenue is not a cost of the regulation since it only reflects an income transfer between the

*Although prices are regulated, it is assumed the CPI is appropriate for converting 1976 rates to 1974 rates.

power company and the electricity users. Therefore, no real costs are associated with a voltage reduction of 2.5% for short periods of time.

23.2 EMISSION REDUCTION EFFECTS OF ACTION 21

Emission reductions are estimated by multiplying an emission factor in tons/kWh by the kWh generated at each power station unit. The emission factors are based on the fuel used and the efficiency of the unit. Complete details of the procedure and data used are provided in Appendix B.

Table 23.4 shows the estimated emissions for each of the Chicago SMSA power plant units with and without load and fuel switching and no reduction in electricity generation. Table 23.5 summarizes the emission reduction with load and fuel switching and reductions of 0, 6, 10, 14.3, 20, and 25% in electricity generation, based on 241,318 MWh.

If interruptible and economy customers use their own peakers, emissions will increase by 0.349 tons HC/day and 9.80 tons NO_x/day. The emission factors used for Commonwealth Edison's peaking units were used to make these estimates (see Appendix B). The emission reductions in Table 23.1 assume a 14.3% reduction in electricity generation and that interruptible and economy customers have their own peakers, i.e.,

$$6.38 - 0.349 = 6.03 \text{ tons HC/day, and}$$

$$237 - 9.8 = 227 \text{ tons } NO_x\text{/day.}$$

23.3 REFERENCES

1. Courtney, A., Commonwealth Edison Company, personal communication (Dec. 1976).

2. Fancher, J., Commonwealth Edison Company, personal communication (July 12, 1976).

3. Fancher, J., Commonwealth Edison Company, personal communication (July 16, 1976).

4. Fancher, J., Commonwealth Edison Company, personal communication (Sept. 20, 1976).

Table 23.4. Estimated Emissions with and without Load and Fuel Switching and No Reduction in Electricity Generation (tons)

Plant Name and Unit # (Chicago SMSA)	Hydrocarbons (tons)			Nitrogen Oxides (tons)		
	A[a]	B[b]	Difference (A-B)	A[a]	B[b]	Difference (A-B)
Crawford, #6	0.001	0	0.001	0.618	0	0.618
Crawford, #7	0.017	0.195	-0.178	10.42	11.7	-1.28
Crawford, #8	0.027	0.471	-0.444	16.2	28.3	-12.1
Fisk, #18	0.171	0.171	0	10.2	10.2	0
Fisk, #19	0.028	0.432	-0.404	16.6	25.9	-9.30
Joliet, #5	0.063	0.063	0	3.79	3.79	0
Joliet, #6	0.229	0.315	-0.086	13.7	18.9	-5.20
Joliet, #7	0.028	0.823	-0.795	16.4	49.4	-33.0
Joliet, #8	0.028	0.866	-0.838	16.4	51.9	-35.5
Ridgeland, #1	0.011	0	0.011	6.36	0	6.36
Ridgeland, #2	0.011	0	0.011	6.62	0	6.62
Ridgeland, #3	0.012	0	0.012	7.11	0	7.11
Ridgeland, #4	0.012	0	0.012	7.12	0	7.12
State Line, #1	0.180	0.180	0	10.8	10.8	0
State Line, #2	0.133	0.133	0	8.01	8.01	0
State Line, #3	0.244	0.279	-0.035	14.6	16.7	-2.10
State Line, #4	0.452	0.489	-0.037	27.1	29.3	-2.20
Waukegan, #5	0.012	0.217	-0.205	6.99	13.0	-6.01
Waukegan, #6	0.009	0.167	-0.158	5.54	10.0	-4.46
Waukegan, #7	0.021	0.474	-0.453	12.8	28.4	-15.6
Waukegan, #8	0.022	0.424	-0.402	13.0	25.4	-12.4
Will County, #1	0.175	0.175	0	10.5	10.5	0
Will County, #2	0.167	0.167	0	10.0	10.0	0
Will County, #3	0.299	0.359	-0.060	17.9	21.6	-3.70
Will County, #4	0.523	0.523	0	31.4	31.4	0
TOTAL EMISSIONS	2.87	6.92	-4.05	300.5	415	-115

[a]With load and fuel switching.

[b]Without load and fuel switching.

Table 23.5. Emission Reduction Effects of Action 21

Reduction in Electricity Generation[a] (%)	HC Emission Reductions (tons)			NO_x Emission Reductions (tons)		
	Steam Plants	Peakers	Total	Steam Plants	Peakers	Total
0	4.05	0	4.05	115	0	115
6	4.70	0.512	5.21	159	14.4	173
10	5.10	0.839	5.94	187	23.6	211
14.3	5.21	1.17	6.38	204	32.8	237
20	5.97	1.57	7.54	250	44.2	294
25	6.09	1.80	7.89	256	50.6	307

[a]Base is 241,318 MWh.

24 CURTAILMENT OF ACTIVITIES IN SELECTED MINING, CONSTRUCTION, RETAIL, WHOLESALE, FINANCIAL, AND SERVICE INDUSTRIES -- ACTION 22

During an emergency all facilities and activities listed below must cease operations: mining and quarrying; contract construction work; wholesale trade establishments; retail trade stores except those dealing primarily in the sale of food or pharmaceuticals; real estate agencies, insurance offices and similar businesses; laundries, cleaners and dryers; beauty and barber shops; photographic studies; amusement and recreational service establishments such as motion picture theaters; automobile repair and service garages; advertising offices; consumer credit reporting, adjustment and collection agencies; printing and duplicating services; rental agencies; and commercial testing laboratories. Table 24.1 summarizes the costs and emission reduction effects of Action 22.

24.1 COSTS OF ACTION 22

The costs of Action 22 include those of notifying the owners, operators, employees and customers of the firms affected; overtime labor to avoid losses

Table 24.1. Summary of the Costs and Emission Reduction Effects of Curtailing Activities in Selected Mining, Construction, Retail, Wholesale, Financial, and Service Industries

Episode Length (days)	Costs ($\$10^3$)					Emission Reductions (tons)	
	Notification	Overtime[a]	Consump. Delays	Rescheduling	Total	HC	NO_x
1	445	9,570	85.2	266	10,400	433	254
2	891	19,100	195	531	20,700	865	508
3	1,340	28,700	328	797	31,200	1,300	762
4	1,780	38,300	486	1,060	41,600	1,730	1,020
5	2,230	47,800	670	1,330	52,000	2,160	1,270

[a]The overtime costs are functions of the expected frequency and duration of an emergency. If this action is used for a yellow or red alert the overtime cost estimates may change. However, the results here are maximum costs of this action for alert stages called at ozone levels < 0.5 ppm and are appropriate for all alert stages called at ozone levels ≥ 0.5 ppm.

in productivity; delays in consumption; and rescheduling operations. Shutdown and start-up costs are assumed to be negligible because in most cases they only involve the locking of doors which is done routinely at the end of every working day.

To estimate the cost of this action, 18 industries that would be affected were identified. These industries, along with the needed information for estimating the costs of Action 22, are listed in Table 24.2. The derivation or source of the sales/receipts and number of large establishment data is quite clear. The wage data are derived as follows: (1) the first quarter payroll data obtained from Refs. 1-4* are converted to an aggregate hourly

Table 24.2. Wage, Employment, and Sale/Receipt Data for Selected Industries in the Chicago SMSA

Major Industry Group and SIC Code	Wage Rate ($/hr)	Employment[a]	Annual Sales/Receipts[b] ($$10^3$)	No. of Large Establishments[c]
Mining and Quarrying (10-14)	6.23	3,557	--	2
Contract Construction (15-17)	7.23	124,858	--	6
Wholesale Trade (50-51)	6.24	224,283	49,986,456	29
Retail Trade, except Food and Drugs (52-59, except 54,591)	3.27	440,710	15,565,225	66
Credit Agencies other than Banks (61)	2.36	18,661	--	3
Insurance (63,64)	5.48	62,398	--	18
Real Estate (65)	4.06	46,926	--	4
Combinations of Real Estate, Insurance, Loan, and Law Offices (66)	4.60	1,267	--	0
Laundry, Cleaning, and Garments (721)	3.00	22,847	326,375	2[g]
Photographic Studios, Portrait, Photofinishing (722,7395)	3.62	4,599	115,436	--
Beauty and Barber Shops (723,724)	2.59	767	159,142	--
Advertising Agencies (731)	7.20	10,311	1,542,838	21[g]
Consumer Credit Reporting, Adjustment, and Collection Agencies (732)	4.12	18,661	39,877[d,e]	3
Mailing, Reproduction, etc. (Printing and Duplicating) (733)	4.12	6,228	380,408[e]	--
Rental and Leasing (7395, 7299)	5.25	3,188	76,652[e,f]	--
Commercial Testing Labs (7397)	5.17	1,521	--	--
Auto Repair, Services, and Garages (75)	4.32	16,987	572,495	0
Motion Pictures, Amusement, and Recreation (78,79)	3.60	24,435	660,962	2

[a]Non-administrative and auxiliary employment.

[b]From Refs. 1-3, adjusted from 1972 to 1974 dollars using consumer price indices (see Table A.6).

[c]From Ref. 4.

[d]Does not include SIC 7321 (mercantile reporting agencies).

[e]Only includes establishments with payrolls.

[f]Only SIC 7395.

[g]Values are for two-digit SIC (i.e., 72 or 73).

*References are listed in Sec. 24.4.

payroll in each industry, (2) the aggregate hourly payroll estimate is divided by the number of employees in each industry reported in Refs. 1-4, and (3) the resulting average hourly wage is adjusted to 1974 dollars using the appropriate consumer price indices in Table A.6.

The employment data are estimated from information provided in Ref. 4. The method used is: (1) from Table 1A in Ref. 4 the percentage change in employment between 1972 and 1973, by two-digit SIC in Illinois, is estimated; (2) from Table 1B in Ref. 4 the statewide ratio of employment in a three- or four-digit SIC industry to employment in the two-digit aggregation is estimated; and (3) the employment in each two-digit SIC in the Chicago SMSA, obtained from Table 3 in Ref. 4, is multiplied by the appropriate growth factor estimated in (1) and by the three- or four-digit allocation factor estimated in (2). For example, the 1974 employment in SIC 731 is estimated as follows:

1. In 1972 there were 105,333 employees in Illinois in miscellaneous business services (SIC 73). In 1973, the employment was 114,524. The growth factor is therefore 114,524/105,333 = 1.09.
2. In 1973, 10,975 of the 114,524 employees in SIC 73 were employed in advertising (SIC 731). The allocation factor is therefore 10,975/114,524 = 0.096.
3. In 1973, 98,956 persons were employed in SIC 73 in the Chicago SMSA. The estimated 1974 employment in SIC 731 in the Chicago SMSA is therefore 98,956 • 1.09 • 0.096 = 10,311.*

Notification Cost

The large facilities affected by Action 22 (i.e., those with more than 500 employees) are assumed to be notified by telephone of the emergency. Passengers not residing with the driver of automobile trips postponed because of Action 22 are assumed to be notified by telephone of changes in plans. The small firms, employees, and patrons of the facilities affected are assumed to be notified of the emergency through radio and TV announcements.

Assuming each telephone call lasts two minutes, the cost of notifying the large firms is:

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*Due to rounding of growth and allocation factors, the value of 1974 employment using this equation is 10,355. The value of 10,311 is obtained if the factors are not rounded off.

$$C = N \cdot (T + W/5040 + \overline{W}/5040) \tag{24.1}$$

where:

$C \equiv$ the cost of notifying large firms,

$N \equiv$ the number of large firms to be notified,

$T \equiv$ the cost of a telephone call,

$W \equiv$ the monthly wage of the person making the telephone call,

$\overline{W} \equiv$ the monthly wage of the person receiving the telephone call, and

The constant 5040 is the number of two-minute time periods in a working month of 21 eight-hour days.

Summing the number of large firms shown in Table 24.2 results in an estimate of $N = 156$. Although this figure is for 1973, it is assumed appropriate for 1974. Assuming the telephone calls are made and received by lower level management personnel, $W = \overline{W} = \$1,416$ (the median monthly salary of a Director of Personnel I as reported in Table A.5). Setting $T = \$0.10$ and substituting the values of N, W, and $\overline{W}$ into Eq. 24.1 results in a large firm notification cost of \$103.26.

To estimate the cost of notifying passengers not residing with the drivers of automobile trips that are canceled, it is assumed that a two-minute telephone call is necessary per passenger affected. Therefore, the passenger notification cost is:

$$C' = N' \cdot (T + 2 \cdot W'/30) \cdot \rho \cdot \lambda \tag{24.2}$$

where:

$C' \equiv$ the passenger notification cost,

$N' \equiv$ the total number of passengers,

$T \equiv$ the cost of a telephone call,

$W' \equiv$ the value of an hour's time for the persons making and receiving telephone calls,

$\rho \equiv$ the fraction of passengers not residing with the driver,

$\lambda \equiv$ the fraction of passengers on trips that are postponed, and

The constant 30 is the number of two-minute time periods in an hour.

The number of passengers, N', is estimated from the data in Table 24.3, which is based on information in Ref. 5. Summing the work, work-related, shopping, social/recreational, and personal business trips provides an estimate of $N' = 2,584,000$ passengers. The cost of a telephone call, T, is assumed

Table 24.3. Number of Automobile Trips and Passengers

Trip Purpose	Thousands of Trips	Thousands of Passengers
Work	1,731	327
Work-Related	512	29
Shopping	1,482	749
School	108	225
Social/Recreational	1,314	1,125
Personal Business	754	354
Other	510	55

to be \$0.10 and the value of W' is assumed to be \$5/hr, which is a mid-range estimate and is about equal to the average wage of production workers in the Chicago SMSA in 1974.

The value of ρ ranges between 0 and 1. For lack of any information ρ is set equal to 0.5, which provides a mid-range estimate of the passenger notification cost for a given value of λ.

The value of λ can also range between 0 and 1; however, some information is available that can narrow this range. By grouping trips as work and work-related (i=1), shopping (i=2), and social/recreational and personal business (i=3), the value of λ is estimated as:

$$\lambda = (L_1 \cdot \tilde{N}_1 + L_2 \cdot \tilde{N}_2 + \lambda \cdot \tilde{N}_3) / \sum_{i=1}^{3} \tilde{N}_i \qquad (24.3)$$

where:

- L_1 ≡ the fraction of work and work-related trips that is postponed,
- $\tilde{N}_1$ ≡ the number of passengers on work and work-related trips,
- L_2 ≡ the fraction of shopping trips postponed,
- $\tilde{N}_2$ ≡ the number of passengers on shopping trips,
- $\bar{\lambda}$ ≡ the fraction of social/recreational and personal business trips postponed, and
- $\tilde{N}_3$ ≡ the number of passengers on social/recreational and personal business trips.

From Table 24.3 the values of $\tilde{N}_1$ = 356,000, $\tilde{N}_2$ = 749,000, and $\tilde{N}_3$ = 1,479,000 are obtained. The number of employees affected by Action 22 is about 33.6% of the total work force. If the percent reduction in work and

work-related trips is proportional to the number of employees affected, then $L_1 = 0.336$. The only stores allowed to remain open are food and drug stores. Based on Ref. 1, only 23.4% of retail sales is in food and drug stores. If the number of trips is proportional to sales, then $L_2 = 1 - 0.234 = 0.766$. Although all social/recreational trips to commercial establishments will be curtailed, trips to parks, beaches, friends' houses, etc., are still allowed. Similarly, personal business trips to doctors' offices, religious establishments, and the like are not curtailed. However, it is assumed that most of the social/recreational and personal business trips are affected by Action 22 and $\bar{\lambda}$ is set equal to 0.9.

Substituting the above values of N_i, L_1, L_2, and $\bar{\lambda}$ into Eq. 24.3 results in an estimate of $\lambda = 0.783$. With $\tilde{\lambda}$ ranging between 0 and 1, the value of λ ranges between 0.268 and 0.841. With $\lambda = 0.783$, $\rho = 0.5$, and the values of N', T and W above, the passenger notification cost is estimated to be $C' = \$438,376/\text{day}$.

The cost of the radio and TV announcements is $6,800/day, as calculated in Appendix D. Assuming the telephone calls are made each day of the emergency (this is done because of the gravity of the situation), the notification cost of an n-day episode is:

$$\bar{C} = (6,800 + 438,376 - 103.26)\cdot n = \$445,279\cdot n \tag{24.4}$$

The notification costs for various length episodes are provided in Table 24.1.

Overtime Cost

It is assumed that whenever possible firms adjust operations to avoid losses in output. For many of the industries affected by Action 22, the overtime adjustment is assumed to be used. (See discussions in Chapters 12 and 22 of why the inventory option is not likely to be used).

The overtime cost for an n-day episode is estimated as:

$$\check{C} = \sum_{j \varepsilon J} 0.5\cdot\tilde{W}_j\cdot 8\cdot P_j\cdot n \tag{24.5}$$

where:

$\check{C} \equiv$ the overtime cost,

$\tilde{W}_j \equiv$ the average hourly wage of employees in industry j,

$P_j \equiv$ the number of employees required to work overtime in industry j,

$J \equiv$ the set of industries affected by Action 22 that uses overtime,

The constant 0.5 reflects the assumption that, on the average, the overtime rate is 1.5 times the normal rate, and

The constant 8 is the number of hours in a working day.

The industries assumed to use the overtime adjustment are listed in Table 24.4 along with the data used in Eq. 24.5 and the resulting overtime cost for a one-day episode. The overtime cost is estimated by assuming that start-up times are negligible and that only non-administrative and non-auxiliary employees will require overtime. The overtime costs for various length episodes are presented in Table 24.1.

Cost of Delayed Consumption

The delay cost of an n-episode is estimated as follows:*

$$\hat{C} = \sum_{t=1}^{n} D \cdot \hat{P}_t = D \cdot \sum_{t=1}^{n} \hat{P}_t \qquad (24.6)$$

Table 24.4. Industries Affected by Action 22 Using the Overtime Adjustment

SIC Code	Wage, W_j[a] ($/hr)	Employment[a]	% Admin. and Auxiliary[b]	Non-Admin., Non-Auxil. Emplmnt., P_j	Overtime Cost, One Day ($\$10^3$)
10-14	6.23	3,557	0.754[c]	3,530	88.0
15-17	7.23	124,858	0.794	123,867	3,582.2
50-51	6.24	224,283	8.38	205,488	5,129.0
721	3.00	22,847	0.643[d]	22,700	272.4
722, 7395	3.62	4,599	0.643[d]	4,569	66.2
731	7.20	10,311	0.643[d]	10,245	295.0
733	4.12	6,228	0.643[d]	6,188	102.0
7397	5.17	1,521	0.643[d]	1,511	31.3
TOTAL	6.32	398,204	5.05	378,098	9,566.1

[a]From Table 22.2.

[b]Estimated from data in Ref. 4.

[c]Average of others in this table except wholesale trade.

[d]Values are for two-digit SICs (i.e., 72 and 73).

*See Chapter 11 for an explanation of Eq. 24.6.

where:

$\hat{C} \equiv$ the delay cost,

$D \equiv$ the average daily expenditures delayed, and

$\hat{P}_t \equiv$ the delay factors.

Consumption delays will occur in the retail trade; beauty and barber shops; rental and leasing; automobile repair; and motion pictures, amusement, and recreation. Delays will occur in the financial industries, e.g., credit agencies and real estate; however, for purely money-transaction industries a delay does not reflect a real cost but an income transfer. For the insurance and real estate industries an episode could result in delays in consumption. Because data on the value of these transactions were not obtained, the transactions are assumed equal to the sales/receipts of the other industries in which delayed consumption occurs. Because delay costs are a small percentage of the total cost of Action 22, the error introduced by this assumption is small.

The total average daily sales/receipts delayed are D = 2 • $17,034,476,000 ÷ 365 = $93,339,594.* Using this value of D and the delay factors in Table 24.5, the delay in consumption costs in Table 24.1 are derived.

Rescheduling Cost

The changing of employee work schedules is required by those industries that use the overtime adjustment. Assuming that five minutes are required per employee, the rescheduling cost for an n-day episode is:

$$\underline{C} = (\underline{N} \cdot \hat{W}/2016) \cdot n \qquad (24.7)$$

where:

$\underline{C} \equiv$ the rescheduling cost,

$\underline{N} \equiv$ the number of employees to be rescheduled,

$\hat{W} \equiv$ the monthly wage rate of the person doing the rescheduling, and

The constant 2016 is the number of five-minute time periods in a working month of 21 eight-hour days.

The number of employees to be rescheduled is $\underline{N}$ = 378,098 (see Table 24.4). Assuming the rescheduling is done by lower level management personnel, then

*See Table 24.2 for sales/receipts data in affected industries. The factor 2 reflects the assumption made for real estate and insurance sales/receipts.

Table 24.5. Assumed Minimum and Maximum Delays and Corresponding Delay Factors

t	Minimum Delay (days)	Maximum Delay (days)	Delay Factors[a] $\hat{P}_t$
1	1	8	0.000913
2	2	9	0.001174
3	3	10	0.001435
4	4	11	0.001695
5	5	12	0.001956

[a] A 10% discount rate is assumed; see Table A.7 and discussion in Sec. 2.1.

$\hat{W}$ = \$1,416 (see Table A.5). Substituting these values of $\underline{N}$ and $\hat{W}$ into Eq. 24.7 results in the rescheduling costs shown in Table 24.1.

24.2 EMISSION REDUCTION EFFECTS OF ACTION 22

The effectiveness of Action 22 is calculated as:

$$R_p = A_p + B_p + G_p \tag{24.8}$$

where:

- R_p ≡ total emission reduction of pollutant p (tons/day);
- p ≡ pollutant: 1= hydrocarbons, 2 = nitrogen oxides;
- A_p ≡ emission reduction of pollutant p due to traffic curtailment (tons/day);
- B_p ≡ emission reduction of pollutant p due to the speed increase of remaining traffic (tons/day); and
- G_p ≡ evaporative emission reduction due to reduced sales of gasoline (tons/day).

The variable A_p is calculated as:

$$A_p = \sum_{j=1}^{4} (V_j + V_j' \cdot \overline{\lambda}) \cdot E_p(S_j)/907{,}184$$

$$+ \sum_{j=1}^{4} \sum_{i=3}^{5} V^*_{ij} \cdot E'_{pi}(S_j)/907{,}184 \tag{24.9}$$

where:

$j \equiv$ traffic segment: 1 = expressway peak, 2 = expressway off-peak, 3 = arterial peak, and 4 = arterial off-peak;

$V_j \equiv$ passenger auto Vmt during traffic segment j due to employees of the affected industries making trips to and from work (miles/day);

$V'_j \equiv$ Vmt during traffic segment j by passenger autos making shopping, personal business, and social/recreational trips (miles/day);

$\overline{\lambda} \equiv$ fraction of V'_j due to the public's use of industries affected by Action 22;

$E_p(S_j) \equiv$ emission rate of pollutant p of passenger autos at average speed S_j (grams/mile);

$i \equiv$ truck class curtailed by the action: 3 = light gasoline trucks, 4 = heavy gasoline trucks, and 5 = heavy diesel trucks;

$V^*_{ij} \equiv$ Vmt of trucks of class i during period j due to trucks with trips originating or ending on commercial land (miles/day);

$E'_{pi}(S_j) \equiv$ emission rate of pollutant p by trucks in vehicle class i at average speed S_j (grams/mile); and

The constant 1/907,184 converts grams to tons.

The variable B_p is calculated as:

$$B_p = \sum_{j=1,3} \sum_{i=1}^{9} \overline{V}_{ij} \cdot [\overline{E}_{pi}(S_j) - \overline{E}_{pi}(S'_j)]/907{,}184 \qquad (24.10)$$

where:

j is summed over the two peak traffic segments which experience an average traffic speed increase;

i is summed over all nine vehicle classes (see Appendix E);

$\overline{V}_{ij} \equiv$ Vmt of class i vehicles during traffic segment j after the action (miles/day);

$\overline{E}_{pi}(S_j) \equiv$ emission rate of pollutant p for vehicles of class i at average speed S_j before the action (grams/mile);

$\overline{E}_{pi}(S'_j) \equiv$ emission rate of pollutant p for vehicles of class i at average speed S'_j after the action; and

The constant 1/907,184 converts grams to tons.

It is estimated that 1,032,204 employees are affected by Action 22; this is approximately 33.60% of the total number of employees in the Chicago SMSA. Out of a total of 82,842,500 passenger auto Vmt per day, 7.9%, 1.4%, 22.6%, and 4.0% consist of travel having work as its purpose during the expressway peak, expressway off-peak, arterial peak, and arterial off-peak traffic segments, respectively; thus, work Vmt figures during the four traffic segments

are equal to 6,544,558 miles/day, 1,159,795 miles/day, 18,722,405 miles/day, and 3,313,700 miles/day, respectively. By multiplying these estimates by 0.336, the Vmt (by workers) curtailed by Action 22 are obtained (see Table 24.6). Multiplying the Vmt estimates of Table 24.6 by the low annual mileage auto emission factors of Tables E.4 and E.5, the emission reduction estimates due to curtailing the work trips of the affected employees are:

HC reduction = 81.9 tons/day, and

NO_x reduction = 45.8 tons/day.

Passenger auto travel is broken down by trip purpose (see Appendix E): work, work-related, shopping, school, social/recreational, personal business, and other. It is assumed that trips by the public to establishments affected by Action 22 are included in the shopping, social/recreational, and personal business categories. Out of a total 82,842,500 passenger auto Vmt, it is estimated that 13.0% and 37.3% consist of travel with these three purposes during the expressway off-peak and arterial off-peak traffic segments, respectively. Corresponding Vmt figures for these periods are 10,769,525 miles/day and 30,900,253 miles/day.

The emissions due to trips by the public to affected establishments are calculated by applying the emission factors from Tables E.4 and E.5 to the Vmt figues: HC emissions = $256 \cdot \overline{\lambda}$ tons/day and NO_x emissions = $196 \cdot \overline{\lambda}$ tons/day. The variable $\overline{\lambda}$ is assumed to be 0.865. This is estimated using Eq. 24.3 and defining N_i as the Vmt for trip purpose group i. With $\overline{\lambda}$ = 0.865, the emission reductions become:

Table 24.6. Vmt Curtailed of Non-government, Nonmanufacturing Workers

Traffic Segment	Vmt Curtailed (V_j in Eq. 24.9)
Expressway Peak	2,198,971
Expressway Off-Peak	389,691
Arterial Peak	6,290,728
Arterial Off-Peak	1,113,403
TOTAL	9,992,793

HC reduction = 221 tons/day, and

NO_x reduction = 170 tons/day.

The Vmt estimates for trucks making trips to and from the affected establishments are based on data obtained from CATS [Ref. 6]. The data from CATS include the daily number of internal eight-county truck trips (i.e., both origins and destinations are in eight-county area) made to commercial establishments,* and the fraction of these trips made by CATS-defined light, medium, and heavy trucks. The Vmt by trucks making trips to commercial facilities are estimated by multiplying the number of trips by the fraction of trips made by each truck type, and by the average trip length for each truck type. The resulting Vmt figures are 1,842,226 miles/day for light trucks, 242,948 miles/day for medium trucks, and 461,666 miles/day for heavy trucks.

The Vmt by trucks having trips originating at commercial facilities are calculated by multiplying the number of trips originating at commercial facilities and having a particular destination (manufacturing, government buildings, etc.) by the fraction of total trips arriving at that destination for each type of truck, by the average length of such trips. The sum of Vmt for all destination categories, excluding commercial facilities, is then the total Vmt of trucks originating at commercial facilites. These are 592,399 miles/day for light trucks, 107,719 miles/day for medium trucks, and 284,424 miles/day for heavy trucks.

Thus, Vmt for the eight-county CATS study area by trucks making internal trips having commercial facilities as origins or destinations are 2,434,625 miles/day for light trucks, 350,667 miles/day for medium trucks, and 746,090 miles/day for heavy trucks. In addition, 13,040 external truck trips that would be affected by Action 22 are made daily (i.e., trips with either origins or destinations not in the eight-county area). Multiplying the number of trips by the fraction of external truck trips by each truck type, and by the average external trip length for each truck type, the external Vmt by trucks making trips to and from commercial facilities are 77,009 miles/day for light trucks, 37,982 miles/day for medium trucks, and 367,674 miles/day for heavy

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*Since the affected establishments are primarily commercial, the CATS data on commercial truck trips provide good estimates of the number of truck trips affected by this action.

trucks. Summing internal and external Vmt estimates, total eight-county Vmt are 2,511,634 miles/day for light trucks, 388,649 miles/day for medium trucks, and 1,113,764 miles/day for heavy trucks.

To convert the eight-county Vmt data to six-county SMSA values, the same procedure is employed that is used in Appendix E. For internal trips about 89.5% of the light truck Vmt, 96.4% of medium truck Vmt, and 90.4% of heavy truck Vmt occur in the SMSA. Applying these proportions to the above Vmt estimates, the SMSA values of 2,247,912 miles/day, 374,658 miles/day, and 1,006,843 miles/day for light, medium, and heavy trucks, respectively, are estimated. The procedure used in Appendix E is also employed to convert the CATS truck categories to the three truck classes used in this study. The resulting Vmt estimates for trucks making trips to and from facilities affected by Action 22 are 1,578,034 miles/day for light gasoline-powered trucks, 1,372,391 miles/day for heavy gasoline-powered trucks, and 678,988 miles/day for heavy diesel trucks.

It is assumed that these truck Vmt estimates are apportioned among the four traffic segments the same as general truck traffic, as discussed in Appendix E: 0.075/0.184/0.216/0.525 for the expressway peak, expressway off-peak, arterial peak, and arterial off-peak traffic segments, respectively. The resulting Vmt estimates by traffic segment (V^*_{ij} in Eq. 24.9) are shown in Table 24.7. Applying the emission factors of Tables E.4 and E.5 to the Vmt data of Table 24.7, according to Eq. 24.9, the truck emission reductions are estimated as:

HC reduction = 60.8 tons/day, and

NO_x reduction = 39.2 tons/day.

The emission reductions due to the curtailment of traffic are:

A_1 = 81.9 + 221 + 60.8 = 364 tons HC/day, and

A_2 = 45.8 + 170 + 39.2 = 255 tons NO_x/day.

From the Vmt data of Table 24.8, it is estimated that the average speed of arterial peak traffic will increase from 11.9 to 21.3 mph; expressway peak traffic will experience a speed increase from 43.7 mph to 48.7 mph. Emission factors for all vehicle classes are calculated at these new average speeds and used to estimate the speed increase effect from Eq. 24.10. The resulting emission changes from the speed increases are:

Table 24.7. Truck Vmt Curtailed by Action 22

Truck Class	Vmt Curtailed (V^*_{ij} in Eq. 24.9) Expressway Peak	Expressway Off-Peak	Arterial Peak	Arterial Off-Peak
Light Gasoline	118,353	290,358	340,855	828,468
Heavy Gasoline	102,929	252,520	296,436	720,505
Heavy Diesel	50,924	124,934	14,661	356,469
TOTAL	272,206	667,812	651,952	1,905,442

Table 24.8. Speed Increase Data

Traffic Segment	Vmt before Action (miles/day)	Vmt after Action (miles/day)	Vmt per Hour After Action	Average Speed After Action[a] (mph)
Expressway Peak	7,451,000	4,979,823	995,965	48.7
Arterial Peak	21,393,000	14,450,320	2,890,064	21.3

[a]Based on peak speed adjustment equations (Appendix F).

HC reduction = 44.1 tons/day, and

NO_x *increase* = 1.24 tons/day.

The evaporative hydrocarbon emission reduction due to reduced gasoline sales, i.e., G_1, is estimated in Appendix G to be 24.6 tons/day. The value of G_2 is equal to zero.

The total effectiveness of Action 22 is then:

R_1 = 364 + 44.1 + 24.6 = 433 tons HC/day, and

R_2 = 255 - 1.24 = 254 tons NO_x/day.

24.3 SENSITIVITY ANALYSIS FOR ACTION 22

The passenger notification cost is a function of the fraction of passengers not residing with the driver, ρ, and the fraction of passenger trips postponed, λ. We set ρ = 0.5 and λ = 0.783.

The value of ρ is somewhere between 0 and 1. If $\lambda = 0.783$, then the passenger notification cost would range between 0 and \$876,752 for a single day. Although this range is large it only affects the total cost of Action 22 for a one-day emergency by less than $\pm$ 5%.

The value of λ ranges between 0.268 and 0.841 as $\tilde{\lambda}$ ranges between 0 and 1 (see Eq. 24.3). If $\rho = 0.5$, then the total cost of Action 22 for a one-day episode would only range between \$10.1 million and \$10.4 million, as $\tilde{\lambda}$ ranges between 0 and 1.

The effectiveness calculations are also a fuction of $\tilde{\lambda}$. As $\tilde{\lambda}$ ranges between 0 and 1, $\bar{\lambda}$ ranges between 0.198 and 0.940, HC emission reductions range between 249 and 448 tons/day, and NO_x emission reductions range between 123 and 268 tons/day. Because the emission reduction estimates are more sensitive to $\tilde{\lambda}$ than the cost estimates, the cost/effectiveness ratios are sensitive to the assumed value of $\tilde{\lambda}$. These range between \$40,600/ton and \$23,200/ton for HC and \$82,100/ton and \$38,000/ton for NO_x.

24.4 REFERENCES

1. *Census of Retail Trade, Area Statistics, Illinois, 1972,* U.S. Department of Commerce, RC72-A-14 (1976).

2. *Census of Selected Service Industries, Area Statistics, Illinois, 1972,* U.S. Department of Commerce, SC72-A-14 (1976).

3. *Census of Wholesale Trade, Area Statistics, Illinois, 1972,* U.S. Department of Commerce, WC72-A-14 (1974).

4. *County Business Patterns, Illinois, 1973,* U.S. Department of Commerce, CBP-73-15 (1974).

5. *Purpose, Mode, Time of Day,* Chicago Area Transportation Study, CATS 372-49 (Nov. 1975).

6. Warnke, J., and D.A. Zavattero, *Motor Truck Freight in the Chicago Region,* Chicago Area Transportation Study (to be published).

25 COST AND EMISSION REDUCTION EFFECTS OF THE OZONE EPISODE REGULATION

In this chapter the cost and effectiveness estimates made in previous chapters are combined in a number of ways in order to evaluate the economic and environmental consequences of the ozone episode regulation. In Sec. 25.1, cost and emission reduction effects are estimated for each of the four episode stages. Annual cost and effectiveness estimates for the ozone episode regulations in the Chicago SMSA and in Illinois are provided in Sec. 25.2, and the annual cost is compared to that of other air pollution regulations in the state and Chicago SMSA. The economic efficiencies (cost per ton of pollutant emission reduced) of the regulation, of the various episode stages, and of the 22 episode actions are discussed in Sec. 25.3. In Sec. 25.4 the regulation's real cost is allocated to the different economic sectors, providing some insights into distributional effects; potential impacts on prices and taxes are also examined. The present ozone regulation (R75-4) is compared with the previous regulation (R72-6) in Sec. 25.5. And in Sec. 25.6 the results of the study are summarized and discussed. Because most of the estimates presented are based on previous calculations, few additional calculations are made here.

25.1 COST AND EMISSION REDUCTION EFFECTS OF THE EPISODE STAGES

The four episode stages defined in the ozone episode regulation, and the ozone concentrations at which they may be called, are: advisory, 0.07 ppm; yellow alert, 0.17 ppm; red alert, 0.3 ppm; and emergency, 0.5 ppm. In this section the actions which make up these stages are combined and the cost and effectiveness of each stage is determined. Because the episode actions are not independent the costs and emission reductions of each episode stage are *not* the simple sums of the costs and emission reductions of the component actions. The cost and emission reduction estimates for the four stages are summarized in Table 25.1.

Advisory

During an advisory no control actions are taken except to notify the public of elevated ozone levels. It is assumed that announcements of an ozone advisory are made by radio and TV; these costs are estimated to be $6,800/day (see Appendix D) for announcements made throughout the day or evening. Because

Table 25.1. Summary of the Cost and Emission Reduction Effects of the Four Episode Stages

Episode Length (days)	Costs ($\$10^3$)				Emission Reductions (tons)							
	Advisory	Yellow Alert	Red Alert	Emergency	Advisory HC	Advisory NO_x	Yellow Alert HC	Yellow Alert NO_x	Red Alert HC	Red Alert NO_x	Emergency HC	Emergency NO_x
1	3.40	108	9,320	36,600	0	0	42.3	69.3	925	492	1,490	953
2	6.80	211	15,400	NA	0	0	84.2	138	1,850	985	NA	NA
3	10.2	313	21,700	NA	0	0	125	206	2,780	1,480	NA	NA
4	13.6	417	27,900	NA	0	0	166	272	3,700	1,970	NA	NA
5	17.0	519	NA[a]	NA	0	0	207	339	NA	NA	NA	NA

[a]Not applicable since it is extremely unlikely that this condition will ever exist.

ozone levels tend to go down during the evening hours, the announcements of an advisory are assumed to occur only during the daylight hours and are one-half the cost estimated in Appendix D, i.e., \$3,400/day.

Although individuals who are susceptible to elevated ozone levels may alter their work or social schedules due to the advisory condition, the costs and emission reduction effects of their actions are assumed to be insignificant.

Yellow Alert

During a yellow alert, Actions 1-6 are in effect. The costs and emission reduction effects of various length yellow alerts are provided in Table 25.2. The calculations of most of these costs can be found in the chapters indicated; the other costs and emission reductions are discussed below.

Cost of a Yellow Alert. Notification costs are those of telephone calls and radio and TV announcements. The telephone cost estimates are provided in Table 25.3. It is assumed that telephone calls to automobile passengers not residing with the driver occur each day of the yellow alert while calls from control agencies to affected establishments are only made on the first day of the alert. Therefore, the telephone notification cost for an n-day epsiode is:

$$C = 30,440 \cdot n + 135 \qquad (25.1)$$

The cost of 10-second radio and TV announcements is estimated to be \$6,800/day (see Appendix D). For a yellow alert it is assumed the average announcement takes 20 seconds, since a number of requests or instructions

Table 25.2. Summary of the Costs and Emission Reduction Effects of a Yellow Alert

Type of Cost, Type of Emission Reduction	Costs, Emission Reductions				
	Costs (10^3) by Episode Length				
Type of Cost	1 Day	2 Days	3 Days	4 Days	5 Days
Notification	44.2	88.2	132	176	220
Rescheduling (8)[a]	0.042	0.083	0.125	0.167	0.209
Review Action Plans (4)	1.15	1.15	1.15	1.15	1.15
Inspect Control Devices (4)	3.80	3.80	3.80	3.80	3.80
Delay of Purchases (3)	1.36	2.73	4.09	5.46	6.82
Net Revenue Loss[b]	56.4	113	169	226	282
Landfill (8)	1.08	2.16	3.24	4.32	5.40
TOTAL COSTS	108	211	313	417	519
	Emission Reductions (tons) by Episode Length				
Type of Emission Reduction	1 Day	2 Days	3 Days	4 Days	5 Days
Hydrocarbons					
Vehicular Sources (3)	31.0	62.0	92.9	124	155
Stationary Sources	11.3	22.2	32.4	42.4	52.3
TOTAL HC REDUCTION	42.3	84.2	125	166	207
Nitrogen Oxides					
Vehicular Sources (3)	22.0	44.0	66.0	88.0	110
Stationary Sources	47.3	94.0	140	184	229
TOTAL NO_x REDUCTION	69.3	138	206	272	339

[a]Numbers in parentheses indicate the chapters from which the information is obtained.

[b]This is the social cost of reduced electricity consumption given the assumptions used in the analysis.

Table 25.3. Telephone Notification Cost for First Day of a Yellow Alert

Those Notified	No. of calls	Cost ($)
Automobile Passengers (3)[a]	114,150	30,440
Incinerator Operators (8)	3	2
Manufacturing Firms (4)	189	125
Power Plants (5)	12	8
TOTALS	114,351	30,575

[a]Numbers in parentheses indicate the chapters from which the information is obtained.

must be made. Thus, the radio and TV notification cost is \$13,600/day and the total notification cost, which is provided in Table 25.2, is:

$$\overline{C} = (30{,}440 + 13{,}600) \cdot n + 135 \qquad (25.2)$$

The only interaction among the yellow alert actions involves those affecting power plant operations, i.e., Actions 3, 4, and 5. Action 3 most likely will result in the power company reducing emissions through load switching. It was assumed for Action 4 that demand would be reduced by 2% and for Action 5 that air conditioning demand would be reduced by 5%. The combined effect is a demand reduction of 3.04%. Table 25.4 presents the daily cost of the combined effects of Actions 3-5 for various demand reductions. For the yellow alert a 3.04% reduction is assumed to occur and a cost of \$56,354/day is used in Table 25.2.

Emission Reduction Effects of a Yellow Alert. The vehicular source emission reductions are obtained from Table 3.1. The stationary source emission reduction for each pollutant is the sum of (1) the incinerator emission reduction in Table 8.1, and (2) the power plant emission reduction assuming load switching and a 3.04% reduction in the demand for electricity (see Table 25.5); this sum is listed for HC and NO_x in Table 25.2.

Table 25.4. Daily Cost of Reduced Electricity Consumption with Load Switching

Reduction in Elec. Demand (%)	Foregone MWh of Elec.	Costs ($): Gross Revenue Loss (A)	Operating Cost Savings (B)	Net Revenue Loss (A - B)[a]
0	0	0	0	0
2	4,826	119,650	76,186	43,464
3.04[b]	7,323	181,547	125,193	56,354
5	12,066	299,119	218,282	80,837
10	24,132	598,232	446,364	151,868

[a]This is the social cost of reduced electricity consumption given the assumptions used in the analysis.

[b]Obtained by interpolation.

Table 25.5. Daily Emission Reductions from Power Plants with Load Switching

Reduction in Elec. Demand (%)	Foregone MWh of Elec.	HC Emission Reductions (tons)			NO_x Emission Reductions (tons)		
		Steam Plants	Peakers	Total	Steam Plants	Peakers	Total
0	0	0	0	0	0	0	0
2	4,826	0.581	0.171	0.752	34.9	4.80	39.7
3.04[a]	7,323	0.703	0.260	0.963	42.2	7.28	49.5
5	12,066	0.934	0.428	1.36	56.0	12.0	68.0
10	24,132	1.50	0.839	2.34	89.7	23.6	113

[a]Obtained by interpolation.

Red Alert

During a red alert, Actions 1-17 are in effect. The costs and emission reduction effects of various length red alerts are provided in Table 25.6. The calculations of most of these costs can be found in the chapters indicated; the other costs and emission reductions are discussed below.

Cost of a Red Alert. Notification costs are due to telephone calls and radio and TV announcements. The telephone notification cost estimates are provided in Table 25.7. It is assumed that telephone calls to automobile passengers not residing with the driver occur each day of the red alert while calls from control agencies to the affected establishments are assumed to be made only on the first day of the red alert. Therefore, the telephone notification cost for an n-day episode is:

$$\tilde{C} = 89{,}739 \cdot n + 865 \qquad (25.3)$$

The cost of 10-second radio and TV announcements is estimated to be \$6,800/day (see Appendix D). For a red alert it is assumed the average announcement takes 30 seconds because of the greater number of actions required during a red alert. Thus, the radio and TV notification cost is \$20,400/day and the total notification cost is:

$$\hat{C} = (89{,}739 + 20{,}400) \cdot n + 865 \qquad (25.4)$$

Table 25.6. Summary of the Costs and Emission Reduction Effects of a Red Alert

Type of Cost, Type of Emission Reduction	Costs, Emission Reductions			
	Costs ($\$10^3$) by Episode Length			
Type of Cost	1 Day	2 Days	3 Days	4 Days
Notification	111	221	331	441
Rescheduling	170	327	493	640
Shut-Down/Start-Up	572	582	592	602
Overtime Adjustment	6,560	10,500	14,500	18,500
Delay	45.0	103	173	256
Child Care	432	865	1,300	1,730
Power Plant Operation	-262	-524	-786	-1,050
Foregone Electricity Consumption	423	846	1,270	1,690
Buying Power (13)[a]	395	792	1,190	1,580
Review Action Plans (4)	1.15	1.15	1.15	1.15
Inspect Control Devices (4)	3.80	3.80	3.80	3.80
Spoilage (12)	29.9	59.8	89.8	120
Landfill (19)	2.70	5.83	8.26	11.4
Canceled Trips (9)	572	1,140	1,720	2,300
Mass-Transit Substitution (10)	21.6	43.3	64.9	86.5
Alternatives to Taxi/Livery Services (9)	160	320	480	640
Diversion of Through Traffic (9)	78.8	158	236	315
TOTAL COSTS	9,320	15,400	21,700	27,900
	Emission Reductions (tons) by Episode Length			
Type of Emission Reduction	1 Day	2 Days	3 Days	4 Days
Hydrocarbons				
Vehicular Sources	255	510	765	1,020
Stationary Sources	670	1,340	2,010	2,680
TOTAL HC REDUCTION	925	1,850	2,780	3,700
Nitrogen Oxides				
Vehicular Sources	161	323	484	645
Stationary Sources	331	662	993	1,320
TOTAL NO_x REDUCTION	492	985	1,480	1,970

[a]Numbers in parentheses indicate the chapters from which the information is obtained.

Table 25.7. Telephone Notification Cost for First Day of a Red Alert

Those Notified	No. of Calls	Cost ($)
Automobile Passengers (10)[a]	336,520	89,739
Fleet Operations (9)	132	87
Government Offices (11, 16)	242	160
Incinerator Operators (19)	3	2
Interruptible/Economy Customers (13)	3	2
Manufacturing Firms (12)	196	130
Parking Facility Operators (10)	417	276
Power Plants (13)	12	8
School Superintendents (17)	302	200
TOTALS	337,827	90,604

[a]Numbers in parentheses indicate the chapters from which the information is obtained.

The rescheduling cost estimates are shown in Table 25.8. With the assumption that large manufacturing firms require a day to start up operations. after an episode ends, the rescheduling cost for an n-day red alert is:

$$C' = 156{,}761 \cdot n + 13{,}216 \qquad (25.5)$$

Table 25.9 summarizes the shut-down/start-up cost estimates. A daily cost occurs to keep the municipal/commercial incinerator equipment from being damaged. The shut-down/start-up cost for an n-day episode is:

$$C'' = 9{,}974 \cdot n + 562{,}308 \qquad (25.6)$$

The overtime adjustment costs of a red alert are provided in Table 25.10. The overtime adjustment cost for transportation and utilities is assumed to include the overtime adjustment cost for gasoline tank trucks (see Chapter 18), i.e., it is assumed that all gasoline tank trucks are in fleets of three or more trucks. With the additional assumption that large manufacturing firms require one day after an episode to start up operations, the overtime adjustment cost of an n-day red alert is:

$$\underline{C} = 3{,}981{,}000 \cdot n + 2{,}577{,}000 \qquad (25.7)$$

The delay cost estimates for various length red alerts are given in Table 25.11; the child-care cost is 80% of that estimated in Chapter 17. It

Table 25.8. Rescheduling Costs for First Day of a Red Alert

Those Rescheduling Activities	Cost ($)
Government Agencies (11)[a]	1,020
Incinerator Operators (19)	84
Manufacturing Operations (12)	13,216
Transportation and Utility Vehicles (9)[b]	113,568
Government Trucks (16)	28,873
TOTAL[c]	156,761

[a]Numbers in parentheses indicate the chapters from which the information is obtained.

[b]Includes gasoline delivery trucks which are also affected by Action 16.

[c]It is assumed that large manufacturing firms require one day to start up operations after an episode. Therefore, the rescheduling cost for an n-day red alert is 156,761•n + 13,216.

Table 25.9. Shut-Down/Start-Up Costs of a Red Alert

Type of Facility	Costs ($) Daily	One-Time
Incinerators (19)[a,b]	9,974	1,608
Manufacturing (12)	--	392,000
Transportation and Utility Vehicles (9)	--	168,700
TOTAL	--	562,308

[a]Numbers in parentheses indicate the chapters from which the information is obtained.

[b]A daily cost occurs because supplemental fuels are required to keep equipment from being damaged.

Table 25.10. Overtime Adjustment Costs of a Red Alert

SIC	Industry	Cost for One Day ($)
20-39	Manufacturing (12)[a]	2,577,000
40-48	Transportation and Utilities (9)[b]	1,340,000
4953	Waste Collection (16, 19)	64,000
	TOTAL[c]	3,981,000

[a]Numbers in parentheses indicate the chapters from which the information is obtained.

[b]Assumed to include trucks used to transport gasoline (see Chapter 18). Includes all transportation, not just SICs 40-47.

[c]It is assumed large manufacturing firms require one day after an episode to start up operations. Therefore, the overtime adjustment cost of an n-day red alert is 3,981,000•n + 2,577,000.

Table 25.11. Delay Costs of a Red Alert

Episode Length (days)	Costs ($$10^3$) by Activity Delayed				
	Truck Deliveries (9)[a]	Government Services (16)	Purch. Incl. Parking (10)	Road Repair	Total
1	19.5	5.67	19.7	0.09	45.0
2	44.5	13.0	45.1	0.209	103
3	75.1	21.9	76.0	0.352	173
4	111	32.4	112	0.521	256

[a]Numbers in parentheses indicate the chapters from which the information is obtained.

is estimated that a maximum of 24.8% and a minimum of 17.5% of the work force in the Chicago SMSA will be laid off during a red alert.* The average of these is about 20%. This percentage is assumed to also apply to working mothers, i.e., only about 80% of the working mothers will have to pay for child-care services when schools are closed because of a red alert.

*Some or all of the trucking, utility, retail, manufacturing, and government employees in the Chicago SMSA will be affected by a red alert.

During a red alert it is assumed that there would be a 5% reduction in electricity demand from Action 12 and a 10% reduction in electricity demand for air conditioning resulting from Action 13; together these two actions result in a total demand reduction of 17,060 MWh. The lost satisfaction to the electric utility customers of foregoing this quantity of electricity is $422,933, which is the sum of the gross revenue losses of Actions 12 and 13 provided in Tables 14.2 (for a 5% reduction) and 15.2 (for a 10% reduction).

In addition, an average of 500 MW/hr or 12,000 MWh/day of electricity is purchased for $396,000/day. This means an estimated 17,060 + 12,000 = 29,060 MWh or 12.0% of the 241,318 MWh generated during a typical episode day is not generated by Commonwealth Edison. The savings in operating costs of a 12% reduction in electricity generation with load and fuel switching is estimated by interpolating between the operating cost savings of a 10% and 20% reduction in output (shown in Table 13.3). The resulting cost saving is $261,835/day.

Interruptible and economy customers of Commonwealth Edison Company are assumed to be closed during a red alert because of Action 10; therefore, there are no permanent savings of the resources used to generate this electricity and the postponement only results in an income redistribution between the power company and the interruptible/economy customers. This implies there is no real cost of not providing these customers with electricity during a red alert.

All of the other cost components of a red alert are obtained directly from the chapters indicated in Table 25.6.

Emission Reduction Effects of a Red Alert. The vehicular source emission reduction is the sum of the curtailment of traffic, speed adjustment, and reduced gasoline sales effects.

Table 25.12 summarizes the Vmt reductions from red alert actions. In most cases the total Vmt reductions are the sums of the Vmt reduction of each action. However, there are some interactions which complicate the calculation. The gasoline tank truck Vmt reduction resulting from Action 16 is assumed to be included in the truck fleet Vmt reductions resulting from Action 7. Similarly, the waste collection truck Vmt reduction of Action 17 is included in the Vmt reduction resulting from the closing of government offices (Action 14). Since some non-government fleet trucks make deliveries to and from government offices,

Table 25.12. Vehicle Miles Traveled (Vmt) Reductions of a Red Alert by Traffic Segment

	Vmt Reductions (miles/day)				
Vehicle Type	Expressway Peak	Expressway Off-Peak	Arterial Peak	Arterial Off-Peak	Total
Low-Mileage Autos (9,10,12,16,17)[a]	667,966	4,848,705	1,849,693	12,544,993	19,911,357
High-Mileage Autos (9)	60,762	149,070	185,527	414,803	810,162
Light Gasoline Trucks (9,16)	50,916	124,912	146,636	356,406	678,870
Heavy Gasoline Trucks (9,16)	153,810	377,347	442,973	1,076,669	2,050,799
Heavy Diesel Trucks (9,16)	95,980	235,472	276,423	671,863	1,279,738
Transit Buses	--	--	--	--	--
School Buses (17)	4,577	4,577	13,029	13,029	35,212
Commercial Buses	--	--	--	--	--
Motorcycles	--	--	--	--	--
TOTAL	1,034,011	5,740,083	2,914,281	15,077,763	24,766,138

[a]Numbers in parentheses indicate the chapter from which the information is obtained.

some of the truck Vmt reductions of Action 14 are included in the truck Vmt reductions of Action 7. To account for this interaction, it is assumed that approximately 67%* of the truck Vmt curtailed by Action 14 is not affected by Action 7.

Substituting the Vmt reductions in Table 25.12 into Eq. 2.12 (with f_{ij} always equal to 1) results in emission reductions of 209 tons HC/day and 159 tons NO_x/day.

The speed adjustment effect from reduced Vmt is estimated using the data in Table 25.13, the speed adjustment Eqs. F.1 and F.2, and Eq. 2.13.** In addition to the speed adjustment effect resulting from reduced Vmt, the curtailment of roadway repairs (Chapter 11) also affects vehicle speeds. The combined speed effect emission reductions are: 30.0 + 2.10 = 32.1 tons HC/day, and 2.72 - 0.410 = 2.31 tons NO_x/day.

*Of the trucks that operate in the Chicago SMSA, 33.0% are subject to the provisions of Action 7. This percentage is assumed appropriate for trucks making deliveries to and from government offices.

**The speed adjustment effect is based on average Vmt emisssion reductions. The impact of schools being in full session, summer session, or recess was not considered (see Chapter 17). The accuracy of the results is not affected by this simplification.

Table 25.13. Speed Increase Data for a Red Alert

Traffic Segment	Vmt before Action (miles/day)	Vmt after Action (miles/day)	Vmt per Hour After Action	Avg. Speed After Action[a] (mph)
Expressway Peak	7,451,000	6,416,989	1,283,398	45.8
Arterial Peak	21,393,000	18,478,719	3,695,744	15.8

[a]Based on peak speed adjustment equations in Appendix F. Does not include the effect of Action 9.

The HC emission reduction resulting from reduced sales of gasoline is estimated using the Vmt reduction data from Table 25.12 in Eq. G.1. This results in an emission reduction of 14.0 tons HC/day.

The total emission reductions from vehicular sources, which appear in Table 25.6, are:

$R_1 = 209 + 32.1 + 14.0 = 255$ tons HC/day, and

$R_2 = 159 + 2.31 = 161$ tons NO_x/day.

The emission reductions from stationary sources are summarized in Table 25.14. Except for power plants, these results come directly from the chapters indicated. Power plant emission reductions result from load and fuel switching and reduced power generation. The total estimated reduction in power generation resulting from a red alert is estimated to be 31,700 MWh* or 13.1% of the typical

Table 25.14. Daily Emission Reductions from Stationary Sources during a Red Alert

Source Type	HC Reduction (tons/day)	NO_x Reduction (tons/day)
Electric Power Generation	6.44	237
Incinerators (19)[a]	10.8	5.57
Manufacturing and Processes (12)	617	88.4
Organic Material Handling (18)	36.0	--
TOTAL	670	331

[a]Numbers in parentheses indicate the chapters from which the information is obtained.

*14,640 MWh from Action 11, 12,066 MWh from Action 12, and 4,954 MWh from Action 13.

episode day's output of 241,318 MWh. The emission reduction in Table 25.14 is obtained by interpolating between the emission reductions for 10% and 20% generation reductions in Table 13.5.

Emergency

During an ozone emergency, Actions 1-22 are in effect. The costs and emission reduction effects of a one-day emergency* are presented in Table 25.15. The calculations of most of these estimates can be found in the chapters indicated; the other costs and emission reduction effects are discussed below.

Cost of an Emergency. All activities except power plant operations are assumed to be affected by Action 18 when most motor vehicle operations are curtailed. Controls on power plant operations are obtained through Actions 12, 13, and 21. Action 18 also does not require reviews of action plans or inspections of control equipment as required in Action 2. Therefore, the costs of an emergency can be estimated from the results presented in Chapters 4, 14, 15, 20, and 23.

The notification cost of an emergency is the sum of the notification cost of Action 18 and 23, i.e., \$735,865 + \$496 = \$736,361/day.

During an emergency it is assumed that there would be a 5% reduction in electricity demand from Action 12, and a 10% reduction in electricity demand for air conditioning from Action 13, resulting in a total demand reduction of 17,060 MWh. The lost satisfaction to the electric utility customers of foregoing this quantity of electricity is \$422,933, which is the sum of the gross revenue losses of Actions 12 and 13 provided in Tables 14.2 (for a 5% reduction) and 15.2 (for a 10% reduction).

In addition, an average of 1,000 MW per hour or 24,000 MWh of electricity is purchased for \$792,000/day. Since 150 MW per hour or 3,600 MWh of output can be eliminated through a voltage reduction of 2.5%, an estimated 17,060 + 24,000 + 3,600 = 44,660 MWh or 18.5% of the 241,318 MWh generated during a typical episode day is not generated by Commonwealth Edison. The savings in operating costs of an 18.5% reduction in electricity generation with load and fuel switching is estimated by interpolating between the operating

*Emergencies lasting longer than one day are extremely unlikely to occur.

Table 25.15. Summary of Costs and Emission Reduction Effects of a One-Day Emergency

Type of Cost, Type of Emission Reduction	Costs, Emission Reductions
Type of Cost	Costs ($\$10^3$)
Notification	736
Rescheduling (20)[a]	652
Shut-Down/Start-Up (20)	3,820
Overtime Adjustment (20)	27,800
Delay Cost (20)	203
Spoilage (20)	107
Landfill (20)	2.70
Diversion of Through Traffic (20)	1,080
Canceled Trips (20)	1,140
Detainment Costs (20)	405
Buying Power (23)	792
Electricity Demand Foregone	423
Power Plant Operation	-564
Review Action Plans (4)	1.15
Inspect Control Devices (4)	3.80
TOTAL COSTS	36,600
Type of Emission Reduction	Emission Reductions (tons)
Hydrocarbons	
Vehicular Sources (20)	774
Stationary Sources	714
TOTAL HC REDUCTION	1,490
Nitrogen Oxides	
Vehicular Sources (20)	504
Stationary Sources	449
TOTAL NO_x REDUCTION	953

[a]Numbers in parentheses indicate the chapters from which the information is obtained.

cost savings of a 10% and 20% reduction in output (shown in Table 23.3). The resulting cost savings is $563,763.

Because Commonwealth Edison's interruptible/economy and large customers will be closed due to Action 20, there is no corresponding customer cost for an emergency as there was for Action 21. Furthermore, electricity consumption by these firms is assumed to be only postponed, i.e., it is purchased when production is made up with overtime labor. Therefore, there is no permanent saving of the resources used to generate this electricity and the postponement only results in an income redistribution between the power company and its larger customers. This implies there is no real cost of not providing these customers with electricity during an emergency.

Some costs that occur if each action is evaluated separately do not occur during an emergency. Child-care costs are no longer relevant because almost all of the working mothers will be at home to take care of their children when schools are closed. Mass-transit substitutes and alternatives to taxi/livery services are no longer relevant since mass-transit vehicles are not operating and most reasons for making these substitutions would be eliminated.

Emission Reduction Effects of an Emergency. The vehicular source emission reduction effects of an emergency are the same as those estimated for Action 18. The stationary source emission reductions are summarized in Table 25.16.

Table 25.16. Daily Emission Reductions from Stationary Sources

Source Type	HC Reduction (tons/day)	NO_x Reduction (tons/day)
Airport Operations (20)[a]	18.7	9.94
Electric Power Generation	8.04	335
Incineration (20)	10.8	5.57
Manufacturing and Processes (20)	640	98.5
Organic Material Handling (20)	36.0	--
TOTAL	714	449

[a]Numbers in parentheses indicate the chapters from which the information is obtained.

To estimate the power plant emission reductions we first observe that the weighted average percent difference between weekend and weekday electricity generated for April, July, and August, 1974, was 20.6%. Because of reduced economic activity during an emergency, at least a 20.6% reduction in electricity generation would be expected if an emergency occurred on a weekday. Assuming the likelihood of an emergency occurring on a weekday is 5/7, then the expected reduction in electricity generation from reduced economic activity would be at least 20.6 • (5/7) = 14.7%.

The electric generation reduction resulting from the purchasing of power, reduced voltage, and required demand reduction will result in an estimated 21.3% reduction in electricity generation. The total electricity generation reduction resulting from an emergency is most likely *not* the sum of the power plant episode action effects and the reduced economic activity effects, i.e., 14.7 + 21.3 = 36%, because of double counting. However, the effect can be bounded between 21.3% and 36%. It is assumed the average of these, 28.7%, is appropriate for estimating the emission reduction effects of an emergency. The estimated emission reductions from power plants with load and fuel switching and a 28.7% reduction in generation are provided in Table 25.16.

25.2 ANNUAL COST AND EFFECTIVENESS OF THE OZONE EPISODE REGULATION

The annual cost and effectiveness of the ozone episode regulation are estimated using the following equation:

$$A = \sum_{i=1}^{4} \sum_{j=1}^{5} f_{ij} \cdot X_{ij} \tag{25.8}$$

where:

$A \equiv$ expected annual cost or emission reduction,

$f_{ij} \equiv$ the frequency of occurrence of episode stage i with a duration of j days,

$X_{ij} \equiv$ the cost or emission reduction of episode stage i with a duration of j days,

$i \equiv$ episode stage: 1 = advisory, 2 = yellow alert, 3 = red alert, and 4 = emergency, and

$j \equiv$ duration of episode: j = 1 to 5 days.

Good estimates of the f_{ij} values are not available. However the Illinois EPA has made preliminary estimates that:

> ... the expected frequencies of various ozone concentrations in Chicago are as follows: 0.07 ppm, 60/1 year; ... 0.17 ppm, 4/1 year; 0.30 ppm, 1/2 years; ... 0.50 ppm, 1/18 years. These data were determined by actual count for low concentrations and by statistical analysis, using the geometric mean and standard geometric deviation of an assumed log normal distribution, for the higher concentrations, i.e., those of 0.20 ppm or more [Ref. 1].*

These data are estimates of the likelihood of reaching ozone levels *necessary* for enacting the advisory, yellow alert, red alert, or emergency episode stages. It is assumed these estimates are also the likelihoods of each of these stages being enacted.**

The number of days and length of period during which meteorological conditions are such that various episode stages *could* occur in a five-year period are provided in Table 25.17. The expected frequency and duration

Table 25.17. Number of Days and Length of Period during which Meteorological Conditions are Such that Various Episode Stages Could Occur in a Five-Year Period

Episode Stage	Number of Days of Occurrence by Length of Meteorological Conditions					
	1 Day	2 Days	3 Days[a]	4 Days[b]	5 Days	Total
Advisory	70	28	14	7	4	123
Yellow Alert	28	11	6	3	2	50
Red Alert	11	6	3	1	0	21
Emergency	4	0	0	0	0	4

Source: Ref. 1.

[a]Assumed to be 1/2 of 2-day occurrences.

[b]Assumed to be 1/2 of 3-day occurrences rounded down (i.e., truncated).

*References are listed in Sec. 25.7.

**This assumption tends to result in an overestimate of the annual cost and effectiveness of the ozone regulation, since reaching these levels is not a *sufficient* condition for enacting each episode stage.

estimates, i.e., the f_{ij} values, in Table 25.18 are estimated by assuming that the likelihood of an x-day episode stage is proportional to the likelihood of the occurrence of the meteorological conditions necessary to support an x-day episode. For example, the likelihood of a 3-day red alert in the Chicago SMSA in a given year is estimated to be: $0.5 \cdot (3/21) = 0.071$.

The values of X_{ij} are provided in Table 25.1. Substituting the values of f_{ij} in Table 25.18 and of X_{ij} in Table 25.1 into Eq. 25.8 results in an estimated annual cost of the ozone episode regulation in the Chicago SMSA of $10 million. This cost does not include the annual cost of preparing action plans or the enforcement and administration costs of the regulation.* The expected annual emission reductions in the Chicago SMSA are:

1,180 tons HC/year, and
970 tons NO_x/year.

A first approximation of the annual cost and effectiveness of the ozone episode regulation in Illinois can be obtained by multiplying the Chicago SMSA results by the ratio of state population to Chicago SMSA population, i.e.,

Table 25.18. Expected Frequency and Duration of Ozone Episode Stages per Year

Episode Length (days)	Annual Frequency of Ozone Episode Stages			
	Advisory (0.07 ppm)[a]	Yellow Alert (0.17 ppm)	Red Alert (0.30 ppm)	Emergency (0.50 ppm)
1	34.15	2.240	0.262	0.0556
2	13.66	0.880	0.143	0
3	6.83	0.480	0.071	0
4	3.41	0.240	0.024	0
5	1.95	0.160	0	0
Total Expected Annual Frequency	60	4	0.50	0.0556

[a]Ozone concentration at which the stage may be called.

*A rough estimate of the annual cost of developing action plans in the Chicago SMSA is $231,000. This is based on an assumed cost of $500/plan by the estimated 1,750 firms requiring to submit an action plan. Furthermore, it is assumed the plans have to be revised every five years.

11,250,500/7,084,600 = 1.59.* However, a better factor is 1.48, which is a weighted average of the Illinois to Chicago SMSA ratios of employment in each 2-digit SIC industry and of population. The weights are the costs of the ozone episode regulation allocated to each 2-digit SIC industry and to government and the general public (see Sec. 25.4). The statewide and Chicago SMSA employment data are obtained from the 1973 County Business Patterns [Ref. 4].

Using the factor 1.48 results in a statewide annual expected cost of \$14.8 million and expected emission reductions of 1,740 tons HC/year and 1,440 tons NO_x/year. These statewide estimates are probably high because the likelihood of each episode stage is most likely greater in the Chicago SMSA than it is elsewhere in the state. However, at this time the data needed to further refine this estimate are not available.

To help evaluate the cost of the ozone episode regulation, it is compared to a number of other cost estimates of air pollution regulations in Illinois; these comparisons are provided in Table 25.19.

Table 25.19. Comparison of the Cost of the Ozone Episode Regulation with Other Air Pollution Regulations

Regulation	Cost[a] ($\$10^6$/yr) Chi. SMSA	Illinois	Source of Information
Ozone Episode	10.0	14.8	--
SO_2 and Particulate[b]	167	--	Ref. 6
Indirect Source[c]	--	25.0	Ref. 3
Federal New Car Standard[d]	253	--	Ref. 8
Mandatory Inspection Maintenance[e]	25.3	--	Ref. 8
Motor Vehicle Noise[f]	--	4.04	Ref. 5

[a]All costs have been converted to 1974 dollars.

[b]Rules 204 a-d, f and 203 a, e, g.

[c]Proposed Complex Source Regulations: Part IX, 3/6/74.

[d]1975 Interim Standards, i.e., emission reductions of 83% HC, 83% CO, and 32% NO_x.

[e]Six-county inspection maintenance program for motor vehicles.

[f]Proposed Motor Vehicle (In-Use) Noise Regulation (R74-10).

*See Tables A.1 and A.4 for population data.

25.3 ECONOMIC EFFICIENCY OF THE OZONE EPISODE ACTIONS AND STAGES

In a cost/effectiveness study economic efficiency is defined as the cost per unit of effectiveness. In this study it is defined as the cost per ton of pollution reduced. However, when more than one effect occurs simultaneously, the concept of efficiency becomes clouded. For example, one action may be highly efficient in reducing HC emissions but very inefficient in reducing NO_x emissions, while another action may be relatively efficient in reducing both pollutants. In such situations, it is difficult to rank these two actions.

Another problem that arises when trying to compare the efficiencies of alternative actions is that the total effectiveness may vary greatly between them. For example, it is difficult to compare a highly efficient but not very effective action and a relatively inefficient and highly effective action.

Because of the difficulties in ranking the efficiency of alternative episode actions and stages, no rankings are presented. Rather, the cost/effectiveness ratios and percent emission reductions of each action and episode stage are presented in Table 25.20 with respect to HC, NO_x, and the sum of HC and NO_x. It should be kept in mind that each action was evaluated assuming no other actions were in effect. Using an alternate assumption, such as all other relevant actions are in effect, could result in significantly different efficiency measures.

The efficiency data in Table 25.20 are based on a two-day yellow and red alert and a one-day emergency. The percent emission reductions are based on the total daily controllable emissions shown in Table 25.21.* Emissions from small man-made and natural sources are not included because estimates of these are not available.

25.4 DISTRIBUTION OF THE COST OF THE OZONE EPISODE REGULATION

Sectoral Costs

In this section the social cost of the episode regulation is apportioned to the following economic sectors: (1) agriculture, forestry, and fishing;

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*For the yellow and red alert the percent emission reduction is relative to two days of emissions since a two-day episode is assumed.

Table 25.20. Economic Efficiencies of Ozone Episode Actions and Stages in the Chicago SMSA[a]

Action Number, Episode Stage	Cost ($\$10^3$)	HC Emission Reductions (tons)	HC Emission Reductions (%)	NO_x Emission Reductions (tons)	NO_x Emission Reductions (%)	Sum of HC and NO_x Emission Reductions (tons)	Sum of HC and NO_x Emission Reductions (%)	Cost Effectiveness ($\$10^3$/ton) HC	Cost Effectiveness ($\$10^3$/ton) NO_x	Cost Effectiveness ($\$10^3$/ton) Total
1	77.2	62.0	2.08	44.0	2.02	106	2.05	1.25	1.75	0.728
2	5.08	0.0	0.0	0.0	0.0	0.0	0.0	NA	NA	NA
3	53.7	0.416	0.0139	24.9	1.14	25.3	0.490	129	2.16	2.12
4	59.0	0.922	0.0309	44.6	2.05	45.5	0.882	64.0	1.32	1.30
5	44.9	0.376	0.0126	16.9	0.777	17.3	0.335	119	2.66	2.60
6	15.8	20.3	0.680	9.59	0.441	29.9	0.580	0.778	1.65	0.529
Yellow Alert	211	83.8	2.81	138	6.34	222	4.30	2.52	1.53	0.951
7	4,750	265	8.88	133	6.11	398	7.71	17.9	35.7	11.9
8	281	220	7.34	152	6.98	372	7.19	1.28	1.85	0.755
9	16.0	4.00	0.134	-0.20	NA[b]	3.80	0.0736	4.00	NA	4.21
10	8,240	1,280	42.9	196	9.01	1,480	28.7	6.44	42.0	5.58
11	1,010	9.72	0.326	326	15.0	336	6.51	104	3.10	3.01
12	127	2.26	0.0757	109	5.01	111	2.15	56.2	1.17	1.14
13	61.1	0.950	0.0318	46.2	2.16	47.2	0.928	64.3	1.32	1.30
14	213	32.0	1.07	14.9	0.685	46.9	0.909	6.67	14.3	4.54
15	1,090	30.4	1.02	11.3	0.519	41.7	0.808	35.9	96.5	26.1
16	107	72.2	2.42	1.52	0.0698	73.7	1.43	1.48	70.4	1.45
17	140	22.0	0.737	12.7	0.584	34.7	0.673	6.36	11.0	4.03
Red Alert	15,400	1,850	62.0	985	45.3	2,840	55.0	8.32	15.6	5.43
18	35,900	1,480	99.2	829	76.2	2,310	89.5	24.3	43.3	15.5
19	1,580	30.7	2.06	21.0	1.93	51.7	2.00	51.5	75.2	30.6
20	19,000	748	50.1	143	13.1	891	34.5	25.4	133	21.3
21	580	6.03	0.404	227	20.9	233	9.03	96.2	2.56	2.49
22	10,400	433	29.0	254	23.3	687	26.6	24.0	40.9	15.1
Emergency	36,600	1,490	99.8	953	87.6	2,440	94.6	24.6	38.4	15.0

[a]Data is for a two-day yellow and red alert and a one-day emergency.

[b]Not applicable.

Table 25.21. Estimated Total Controllable HC and NO_x Emissions in the Chicago SMSA

Source	HC (tons/day)	NO_x (tons/day)	Sum of HC and NO_x (tons/day)
Airports	18.7	9.94	28.6
Gasoline Storage, Transport, and Sales	83.9	--	83.9
Incinerators	10.9	6.21	17.1
Motor Vehicles	730.0	507.3	1,236.9
Power Plants	8.73	466.1	474.8
Stationary Sources (e.g., Manufacturing)	640.0	98.5	738.5
TOTAL	1,491.8	1,088.1	2,579.8

(2) mining and quarrying; (3) construction; (4) manufacturing; (5) transportation, except government (includes all trucking, not just that in SICs 40-47); (6) electric, gas, and telephone utilities; (7) wholesale trade; (8) retail trade; (9) financial, insurance, and real estate; (10) service industries; (11) government; and (12) the public.

The distribution of the social cost of the regulation differs from the distribution of private costs because some income redistribution effects are not considered. However, the major distributional effects of the regulation are captured. This is true because many of the estimated social costs are borne by a clearly defined private enterprise (e.g., overtime costs in the manufacturing sector). Furthermore, the social cost of delayed consumption, which is a loss in satisfaction to the consumer, can also be interpreted as a loss to establishments in the retail and service industries. The costs related to power plants can be interpreted as the social cost of reduced satisfaction plus the resource gain of reduced electricity generation, or it can be interpreted as the net revenue loss to the power company.

The income redistributions that are not accounted for are those that may occur among the different economic sectors listed above. However, it is clear that the sum of the distributional effects must be zero.*

*This is true provided imports and exports are not greatly affected.

The distribution of the social cost of the ozone episode regulation is presented in Table 25.22. Except for the allocation of the notification, delay or foregone consumption, and fleet vehicle costs, the costs assigned to each sector are fairly straightforward. The notification costs are allocated to each sector as follows: (1) the radio and TV announcements, automobile passenger, and half the airline passenger costs are allocated to the public;* (2) half the airline passenger costs are allocated to the transportation industry; (3) half the non-passenger telephone notification costs are assigned to government (i.e., it is assumed these calls are made by environmental control agencies); and (4) half the non-passenger telephone calls are allocated to the industries notified. The delayed or foregone consumption cost is allocated to the retail and service sectors in proportion to their relative sales/receipts in 1972. The delayed freight cost is assumed to primarily affect the manufacturing industry. The fleet vehicle costs are apportioned to the transportation, utility, and service (rental cars) sectors in proportion to the relative number of fleet vehicles in each of these sectors.

Price Effects

To estimate the potential price effects of the ozone episode regulation, we use the Leontief input-output system [Ref. 2]:

$$P = P \cdot A + V \tag{25.9}$$

$$P = V \cdot (I-A)^{-1} = V \cdot \overline{A} \tag{25.10}$$

where:

$P \equiv$ the price vector $(p_1, p_2, \ldots, p_n)$ for commodities 1 through n,

$A \equiv$ the direct input matrix $[a_{ij}]$,

$V \equiv$ the value added vector $(v_1, v_2, \ldots, v_n)$ for commodities 1 through n,

$I \equiv$ the identity matrix, and

$\overline{A} \equiv$ the technology matrix $[\overline{a}_{ij}]$.

A single equation in the system of price equations defined by Eq. 25.9 is:

$$p_j = p_1 \cdot a_{1j} + p_2 \cdot a_{2j} + \ldots + p_n \cdot a_{nj} + v_j \tag{25.11}$$

where:

*Radio and TV costs are not allocated to the communication industry because they do not reflect expenditures made by them.

Table 25.22. Distribution of Social Cost of Ozone Episode Regulation

		Costs ($$10^3$)												
Episode Stage	Episode Length (days)	Agric., Forestry, Fishing (01-09)[a]	Mining, Quarying (10-14)	Const. (15-17)	Mfg. (20-39)	Transport.[b] (non-govt.)	Electric, Gas & Tel. Utilities (48,49)	Whole-sale Trade (50-51)	Retail Trade (50-59)	Finance, Insur., Real Est. (60-67)	Service Ind. (non-govt.) (70-89)	Govt.[c]	Public	Total[d]
Advisory	1	0	0	0	0	0	0	0	0	0	0	0	3.40	3.40
	2	0	0	0	0	0	0	0	0	0	0	0	6.80	6.80
	3	0	0	0	0	0	0	0	0	0	0	0	10.2	10.2
	4	0	0	0	0	0	0	0	0	0	0	0	13.6	13.6
	5	0	0	0	0	0	0	0	0	0	0	0	17.0	17.0
Yellow Alert	1	0	0	0	6.09	0	56.4	0	1.28	0	0.080	0.109	44.0	108
	2	0	0	0	7.17	0	113	0	2.57	0	0.162	0.150	88.1	211
	3	0	0	0	8.25	0	169	0	3.85	0	0.243	0.192	132	313
	4	0	0	0	9.33	0	226	0	5.14	0	0.324	0.234	176	417
	5	0	0	0	10.4	0	282	0	6.42	0	0.404	0.276	220	519
Red Alert	1	0	0	0	5,610	1,720	768	0	283	0	102	108	723	9,320
	2	0	0	0	8,230	3,280	1,540	0	576	0	208	214	1,450	15,400
	3	0	0	0	10,900	4,830	2,300	0	877	0	316	320	2,170	21,700
	4	0	0	0	13,500	6,380	3,070	0	1,190	0	428	426	2,890	27,900
Emergency	1	0	90.5	3,670	19,200	4,260	863	5,270	601	0.008	734	108	1,800	36,600
Expected Annual Cost for Chicago SMSA		0	5.03	204	4,840	1,650	1,110	293	290	0.0004	131	98.4	1,400	10,000
Expected Annual Cost for Illinois[e]		0	30.0	304	6,990	2,140	1,910	377	434	0.0005	181	156	2,230	14,800

[a]Numbers in parentheses are SIC codes.

[b]Includes all transportation (e.g., retail store and manufacturing firm trucks), except government. Therefore, it includes but is not limited to SICs 40-47.

[c]Does not include enforcement and administrative costs of ozone episode regulation.

[d]Does not include cost of preparing action plans.

[e]Based on ratios of population or employment in appropriate economic sectors between the state and the Chicago SMSA.

where:

$p_i \equiv$ the price of good i (i = 1,...,n),

$a_{ij} \equiv$ the quantity of good i used to produce a unit of good j, and

$v_j \equiv$ the value added per unit of good j.

Eq. 25.11 simply states that the price of a product is equal to the cost of the inputs required to make the product. The primary factor inputs, including returns to entrepreneural skills (i.e., profit), are incorporated in the value added term. From Eq. 25.10, the price of good j is equal to:

$$p_j = v_1 \cdot \bar{a}_{1j} + v_2 \cdot \bar{a}_{2j} + \ldots + v_n \cdot \bar{a}_{nj} \tag{25.12}$$

Now, if the value added in each industry is increased by the same factor, say d, then the price of each good will also increase by a factor of d, i.e.

$$d \cdot p_j = d \cdot (v_1 \cdot \bar{a}_{1j} + v_2 \cdot \bar{a}_{2j} + \ldots + v_n \cdot \bar{a}_{nj})$$

For simplicity it is assumed that all of the costs of the ozone episode regulation are additions to value added or primary factors of production. This assumption is reasonable since the bulk of the costs of the ozone episode regulation are increases in labor costs (e.g., overtime) which is an increase in the cost of the primary factors of production.

From Appendix C the value added (value of the primary factors of production) is obtained for the ten industrial sectors given in Table 25.22. Dividing the cost in each of these industries provided in Table 25.22 by the value added data in Appendix C provides estimates of the fractional increase in the value added in each industry due to the episode regulation. The largest fractional increase is 0.0970%, which occurs in the utility industry (SICs 48 and 49). Assuming all industries experience this increase, i.e., d = 0.0970 ≃ 0.10, implies that the *maximum* price increase for all commodities is only 0.10%.

Tax Increase

The potential tax increase is estimated by assuming the government costs are totally financed by a tax increase. The cost of the ozone episode regulation to government is estimated to be \$156,000/yr in Illinois in 1974. (This does not include the costs of enforcing and administering the regulation.

These omitted costs are probably the major government costs, but much of these costs is already budgeted). Assuming the percent change in population between 1974 and 1972 is the same as between 1972 and 1970 (see Table A.4), the 1974 population in Illinois is 11,389,934. This implies a tax increase of less than 1.4 cents per person per year. The tax burden per household is estimated to be 4.25 cents (in 1970 there were 3.1 persons/household [Ref. 7]).

25.5 COST EFFECTIVENESS COMPARISON OF REGULATIONS PCB R75-4 AND PCB R72-6

The *new* ozone episode regulation being evaluated in this document (i.e., PCB R75-4) is now compared to the previous ozone episode regulation (i.e., PCB R72-6). Using a set of reasonable assumptions the old regulation would result in the same control actions during an ozone watch (an advisory in the new regulation), yellow alert, and emergency.* Possible exceptions include the control of manufacturing establishments during a yellow alert and of power plants during an emergency. Under the provisions of the old regulation, manufacturing plants that violate Illinois emission standards, even if given a variance, would be required to reduce emissions to the standard during a yellow alert. Under the provisions of the new regulation no emission reductions are required during the yellow alert stage. During an emergency, the old regulation does not explicitly require power plants to buy power, reduce sales to large customers, or reduce voltage. Therefore, it is possible that these actions would not be taken. However, to make a base case comparison of the two regulations the control actions for a watch (advisory), yellow alert, and emergency are assumed to be identical for R72-6 and R75-4. The effect of this assumption on the sensitivity of the comparison is discussed later in this section.

One of the major differences in the two regulations is the control requirements during a red alert. In particular, the old regulation does not include any controls on vehicles except to request the public to reduce unnecessary use of automobiles (i.e., Action 1). In addition, government agencies and schools are not closed and the loading and unloading of volatile organic material is not prohibited during a red alert. Therefore, for the base case comparison it is assumed that the control actions during a red alert

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*The assumptions used take into account the discretionary power given to the Illinois EPA in Rule 404 of R72-6.

under the old regulation consist of requesting the public to avoid unnecessary use of automobiles (Action 1) and electricity (Actions 12 and 13), curtailing operations of large polluters (Action 10), altering power plant operations (Action 13), and curtailing incinerator operations (Action 17).

The curtailment of road repairs (Action 9) could occur during all episode stages under the old episode regulation as a result of Rule 205 (f) (2) (c) of the Illinois emission standards (i.e., PCB R71-23). However, inclusion of Action 9 will not significantly affect the results and, therefore, Action 9 is ignored in this comparison.

Using these base case assumptions the costs and emission reduction effects of a watch (advisory), yellow alert, and emergency lasting n days under the old regulation are the same as under the new regulation, i.e., the costs given in Table 25.1. The costs of a red alert under the old regulation are estimated to be \$6,230, \$9,470, \$11,000, \$16,000, and \$19,200 for one- to five-day episodes, respectively. The emission reduction effects are 695 tons HC/day and 363 tons NO_x/day.

Another major distinction between the two regulations is the levels of ozone required to trigger each episode stage. The watch trigger level is identical to the advisory level of 0.07 ppm. However, for the old regulation a yellow alert could be called when ozone levels reached 0.10 ppm rather than 0.17 ppm which is the trigger point for the new regulation. This difference means that under the old regulation yellow alerts in the Chicago SMSA could be called an estimated 22 times a year as compared to 4 times a year under the new regulation [Ref. 1]. On the other hand, it is estimated that the old regulation would only result in a red alert being called in the Chicago SMSA once every 5 years rather than once every 2 years because the trigger level for a red alert is 0.40 ppm as compared to 0.30 ppm. The Illinois EPA estimates that ozone levels in Chicago are not expected to ever exceed 0.60 ppm, the trigger point for an emergency under the old regulation. This compares to an expected frequency of once every 18 years of ozone levels exceeding 0.50 ppm.

The net effect of the changes in the levels at which each stage is called is to make the yellow alert stage under the old regulation the most important, whereas the red alert stage is the most important under the new regulation.

Using the data provided by the Illinois EPA on the frequency and duration of alternative levels of ozone [Ref. 1] and the procedure described above for estimating the expected annual cost and emission reduction effects of the ozone episode regulation, the estimated annual cost of the old regulation is \$6.30 million in the Chicago SMSA and \$9.32 million in Illinois.* The expected annual emission reductions are 1,820 tons HC and 2,750 tons NO_x in the Chicago SMSA and 2,690 tons HC and 4,070 tons NO_x in Illinois. The cost/effectiveness ratios are \$3,460/ton HC, \$2,290/ton NO_x, and \$1,380/ton HC and NO_x.

For the base case comparison the new ozone regulation results in an expected annual cost *increase* of $(10 - 6.3) \cdot 100/6.3 = 59\%$. However, the expected annual emission reductions *decrease* by 35% for HC and by 65% for NO_x. Therefore, on an annual expected value basis, the old regulation is more efficient than the new one.

However, this comparison is incomplete. An in-depth analysis reveals that 64% of the expected annual HC and 31% of the expected annual NO_x emission reduction of the old regulation are from the voluntary curtailment of automobile use, Action 1. For the new regulation only 19% and 16% of the expected annual HC and NO_x emission reductions, respectively, are from Action 1. Since the impact of this provision of the regulation may become less effective the more frequently the public is requested to reduce travel, the effect of the old regulation may be seriously undermined for the same reason its efficiency and expected annual emission reductions are high, i.e., yellow alerts are expected to occur frequently.

Furthermore, about 88% of the HC expected annual emission reduction and 96% of the NO_x expected annual emission reduction occur at relatively low ozone levels with the old regulation, i.e., at the yellow alert stage. For the new regulation all the emission reductions occur after 0.17 ppm and more than 74% of the HC and 49% of the NO_x reductions occur at levels greater than 0.30 ppm. At the red alert stage (where a major difference in the regulations occurs) the new regulation is 33% and 26% more effective in reducing HC and NO_x emissions, respectively. This means that the new regulation provides better protection for periods of time when ozone levels are very high while the old regulation provides better protection at lower ozone levels.

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*The expected frequency of an emergency is assumed to be once every 100 years rather than assuming it would never occur.

The above analysis is not affected by the assumptions made on the power plant controls because only the cost and effects of a red alert and emergency are affected and the probability of these conditions occurring is small. For example, if the required power plant controls during a red alert and emergency are assumed to be the same as the yellow alert controls, the estimated annual cost of the old regulation would only be reduced by 2.5%. However, the assumption that no emission reductions will occur from manufacturing establishments during a yellow alert under the old regulation is extremely important because of the relatively large number of yellow alerts that could occur at the 0.10 ppm level. For example, if 10% of the cost and effectiveness of Action 10 would occur during a yellow alert, the annual expected cost of the old regulation would increase by more than 357% to $22.5 million* in the Chicago SMSA and $33.3 million in Illinois. Although emission reductions would also increase drastically (i.e., 234% for HC and 114% for NO_x), the efficiency of the old regulation would be significantly reduced.

The above discussion reveals that the two regulations differ in terms of expected annual cost and effectiveness. If very few manufacturing firms are affected during a yellow alert under the old rules, then the comparison of the old and new regulations based on annual expected cost and emission reductions favors the old regulation. However, this advantage could be eliminated if persons do not voluntarily curtail driving and if some manufacturing firms that violate emission limits have to close down. The added cost of the new regulation seems to be a result of obtaining more protection during periods of relatively high ozone levels.

For the base case assumptions, Table 25.23 summarizes the cost and effectiveness differences between the two ozone episode regulations.

25.6 DISCUSSION OF RESULTS

Annual Cost

The annual cost of the ozone episode regulation in the Chicago SMSA is estimated to be $10 million. (This does not include the cost of developing action plans or enforcement and administration costs.) The expected annual

*This is an overestimate because it assumes the overtime option is used. Because of the frequency of a yellow alert the inventory option would be cheaper (see Chapter 12).

Table 25.23. Cost/Effectiveness Comparison of R75-4 and R72-6[a]

Episode Stage	Episode Ozone Levels (ppm)		Episode Length (days)	Cost ($10³)		HC Emission Reduction (tons)		NO_x Emission Reduction (tons)		Cost/Effectiveness Ratios ($10³/ton)					
										HC		NO_x		Sum	
	R75-4	R72-6		R75-4	R72-6	R75-4	R72-6	R75-4	R72-6	R75-4	R72-6	R75-4	R72-6	R75-4	R72-6
Advisory (Watch)	0.07 (60)[b]	0.07 (60)	1	3.40	3.40	0	0	0	0	--	--	--	--	--	--
			2	6.80	6.80	0	0	0	0	--	--	--	--	--	--
			3	10.2	10.2	0	0	0	0	--	--	--	--	--	--
			4	13.6	13.6	0	0	0	0	--	--	--	--	--	--
			5	17.0	17.0	0	0	0	0	--	--	--	--	--	--
Yellow Alert	0.17 (4)	0.10 (22)	1	108	108	42.3	42.3	69.3	69.3	2.55	2.55	1.56	1.56	0.968	0.968
			2	211	211	84.2	84.2	138	138	2.51	2.51	1.53	1.53	0.950	0.950
			3	313	313	125	125	206	206	2.50	2.50	1.52	1.52	0.946	0.946
			4	417	417	166	166	272	272	2.51	2.51	1.53	1.53	0.952	0.952
			5	519	519	207	207	339	339	2.51	2.51	1.53	1.53	0.952	0.952
Red Alert	0.30 (1/2)	0.40 (1/5)	1	9,320	6,230	925	695	492	363	10.1	8.96	18.9	17.2	6.58	5.89
			2	15,400	9,470	1,850	1,390	985	725	8.32	6.81	15.6	13.1	5.43	4.48
			3	21,700	11,000	2,780	2,085	1,480	1,088	7.81	5.28	14.7	10.1	5.09	3.47
			4	27,900	NA[c]	3,700	NA	1,970	NA	7.54	--	14.2	--	4.92	--
Emergency	0.50 (1/18)	0.60 (1/100)	1	36,600	36,600	1,490	1,490	953	953	24.6	24.6	38.4	38.4	15.0	15.0
Expected Annual Value Chicago SMSA	--	--	-	10,000	6,300	1,180	1,820	970	2,750	8.47	3.46	10.3	2.29	4.65	1.38
Expected Annual Value Illinois[d]	--	--	-	14,800	9,320	1,740	2,690	1,440	4,070	8.47	3.46	10.3	2.29	4.65	1.38

[a] Comparison uses base case assumption that advisory, yellow alert, and emergency control actions are identical for both regulations.

[b] Numbers in parentheses are the expected number of days that oxidant concentrations exceed the trigger levels in the Chicago SMSA per year [Ref. 1]. It is assumed this is equal to the number of times each episode stage is expected to occur each year.

[c] Not applicable since it is extremely unlikely that this condition will ever exist.

[d] The Illinois values are 1.48 times the Chicago SMSA values. This is probably high because the frequency of occurrence of each episode stage is probably less outside the Chicago SMSA.

costs for each episode stage are \$358,000 for an advisory, \$761,000 for a yellow alert, \$6,850,000 for a red alert, and \$2,040,000 for an emergency. Therefore, more than 68% of the expected annual cost of the regulation is due to the red alert actions and 20% is due to the emergency actions.

This result is highly sensitive to the expected frequencies of the red alert and emergency stages. For example, if the expected frequency of a red alert is actually closer to once every four years than once every two years as assumed in the analysis, then the expected annual cost of the red alert would be halved and the total annual expected cost of the ozone regulation would be reduced by 34%.

The converse is not necessarily true, i.e., if red alerts occur three times in four years the expected annual cost might not increase by 34%. The reason is that the inventory adjustment becomes less expensive than the overtime adjustment as the frequency of red alerts increases. Therefore, the cost of a red alert is not proportional to increased frequency of occurrence. However, as a first approximation a proportional increase in costs is appropriate.

Disaggregating the annual cost by cost type reveals that about 62.4% of the annual cost estimate is a result of the overtime adjustments. Therefore, by far the most important assumptions in the analysis are those that affect the overtime adjustment cost. For manufacturing firms, the overtime adjustment cost and the inventory adjustment cost are compared extensively. For the estimated frequencies of occurrence of each episode stage used in this study, the overtime adjustment is the less expensive.

Either of these two adjustments is assumed to occur to avoid losses in production. It is possible that neither of these adjustments will be used and production will decline. In this case the value of the reduced supplies of goods would be the social cost. However, if any lost production of a good is valued at its market price, then the overtime adjustment would be less expensive than reduced production if half the wage rate per unit of good produced is less than its price. Furthermore, with a reasonable degree of competition among suppliers of goods, the overtime adjustment is more likely to be used than the reduced production option to maintain market shares or satisfy customer requirements. For these reasons, we feel the use of the overtime adjustment is warranted.

Accepting the premise that production levels will be maintained, the use of overtime should be examined closely. It is assumed that all production worker, truck driver, miner, construction worker, and other blue collar worker man-hours lost during an episode will be made up using overtime labor and that other workers do not require overtime. If the blue-collar workers are not required to work more than 40 hours a week to make up the lost production and if weekend work is not considered overtime, it is possible to make up lost production without the need to use overtime labor. If this situation occurs then the estimated overtime cost is overstated.

On the other hand, white collar hourly workers, such as secretaries, clerks, etc., are assumed to make up the lost man-hours without overtime. This was done in part to account for the fact that some blue collar workers will not require overtime.*

Employees in the retail and service industries most likely will not require overtime because their productivity is demand determined. For example, a sales person can usually sell more products in a normal working day if more customers are shopping. Although there is an upper bound to a retail or service employee's productivity, we feel the increased demands after an episode will not result in these upper bounds being reached. If this assumption is invalid, then the overtime cost is probably underestimated.

Finally, it has been assumed that salaried employees and professionals do not require overtime. This is based on the assumption that their salaries already reflect the fact that they work irregular hours or shifts. Therefore, substituting weekend work for week days lost during an episode does not involve any social cost. Furthermore, some salaried employees' work can be done at home during an episode (e.g., reading reports and professional journals, drafting letters and reports, and the like). If these assumptions are invalid, then the overtime adjustment cost is underestimated.

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*It could have been assumed that a fraction of blue collar and white collar workers require overtime and the rest do not. This was not done because of a lack of data and because it would complicate the analysis without improving the results. For example, if it had been assumed that all workers in the manufacturing industries require overtime (i.e., not just production workers), then the total cost of the regulation would only increase by about 15%.

The above discussion indicates that although there are some uncertainties about the overtime adjustment cost estimates, these estimates are reasonable. Given the time and resources available to do this project, the overtime adjustment estimate is as accurate as possible. Because of the importance of this cost component to the total cost estimate of the regulation, confidence in the overtime cost estimate lends confidence to the total cost estimate.

The second most important cost components are those associated with controls on power plants: the cost of buying power, load switching, and fuel switching; the lost satisfaction to customers from reduced electricity consumption; the cost of substituting some other energy source by interruptible/economy or large electricity customers; and the savings in resources resulting from reduced power generation. The sum of these costs accounts for about nine percent of the total expected annual cost of the regulation.

Since most of the information used to estimate these costs came directly from Commonwealth Edison Company data and records, we have a great deal of confidence in these cost estimates. However, it should be kept in mind that the estimates are based on an assumed "typical episode day" in which 241,318 MWh of electricity is normally generated with a peak hourly demand of 11,500 MW. Furthermore, it is assumed that natural gas will be available for fuel switching and that a reasonable quantity of electricity will be available to purchase. All of these conditions are subject to considerable variation. Therefore, for any given episode condition the costs and effectiveness of the power plant control option could vary significantly from the typical day estimate used in the analysis. We feel our estimates reflect an accurate expected or average condition.

The third most important cost component is the notification cost, which represents about eight percent of the total estimated annual cost of the ozone episode regulation. At least half of this is the cost of radio and TV announcements. Interestingly enough, more than 3.5% of the annual cost of the regulation is for radio and TV announcements during advisory conditions; this is a direct consequence of the frequency of advisory conditions.

Although the notification cost is a relatively large component of the total cost of the regulation, it should be kept in mind that this cost, in general, does not reflect cash outlays by any group or individual. For

example, no one has to pay for the radio and TV announcements since they are broadcast as a public service. In addition, the radio and TV stations would not lose any revenues because no advertising time would be lost. This distinction between a pecuniary and a real cost is important to understand but it does not mean these notification costs are any less important than other costs which do involve cash expenditures.

The sum of the overtime, power plant, and notification costs is about 80% of the total annual cost. None of the other cost components contributes more than 5.6% of the total cost and most of them contribute less than one percent. Therefore, the uncertainties in estimating the other cost components have little impact on the total annual cost estimate. This should be kept in mind when trying to interpret the results of the study.

Of particular interest is the contribution of delay costs. They are less than 0.7% of the total cost. This is important because the delay cost is the primary cost component of actions that restrict shopping or recreational activities.

Finally, it should be mentioned that one important cost component is not included in the analysis: the psychic or inconvenience cost associated with the regulation. For many actions this cost could be quite significant. For example, individuals who have planned a vacation trip may experience considerable displeasure if their trip has to be canceled or delayed. Similarly, businessmen trying to meet deadlines may experience increased anxieties or frustrations if their work is stopped due to an episode. Although these costs are difficult to estimate they are nevertheless real and should not be forgotten simply because empirical estimates of them are not available.

Efficiency of the Regulation

A detailed analysis of Table 25.20 reveals some interesting insights concerning the design of the ozone episode regulation. To begin with, the cost of reducing the sum of HC and NO_x emissions during an episode increases at an increasing rate. That is, for small reductions in emissions the cost per ton reduced is relatively small. As the total quantity of emission reductions increases, the cost per ton reduced increases. A consequence of this fact is that the cost per ton of the sum of HC and NO_x emission reductions

are \$951, \$5,430, and \$15,000 for a yellow alert, red alert, and emergency, respectively; the percent emission reductions are 4.30%, 55.0%, and 94.6%, respectively.

The most efficient control actions are those that restrict shopping and social/recreational trips, Actions 1 and 8. This is a direct result of the fact that the delay costs are small and that overtime is probably not required in the retail and service industries. However, the absolute effectiveness of these actions is relatively small and depends heavily on public reaction. For example, if few trips are canceled or many substitute trips are made, the emission reductions will be small. In the latter case, the cost/effectiveness ratios will increase.

Another very efficient strategy is the control of small incinerator operations. If waste collection operations are not affected by the closure of municipal/commercial incinerators, then controlling all incinerator operations is quite efficient (see Chapter 19). Although control of incinerators (Actions 6 and 17) is efficient, the potential effectiveness is very small, since incinerators account for only 0.731% and 0.571% of the controllable hydrocarbon and nitrogen oxide emissions in the Chicago SMSA.*

On the other end of the spectrum, the least efficient strategies are, in general, the actions that restrict production or trucking operations: Actions 7, 18, 20, and 22. This result is a direct consequence of the assertion that overtime is highly likely to be required to adjust to these control actions. Although these actions are the least efficient, they have the greatest emission reduction potential of all the episode control actions.

Action 10, the closing of large stationary pollution sources, is an interesting exception to the finding that actions requiring significant overtime to make up lost man-hours are the least efficient and that relatively efficient control strategies are the least effective in reducing emissions. Action 10 results in relatively large emission reductions more efficiently than other actions with large overtime costs because the fraction of employment in large polluting industries is small relative to the fraction of the pollution emitted by them.

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*The potential effectiveness of controlling small incinerators is actually unknown (see Chapter 8). However, it is expected to be small.

The closing of schools, Action 15, and the curtailment of aircraft departures, Action 19, both have relatively high cost/effectiveness ratios and relatively small emission reduction effects. Action 15 also has relatively large cost/effectiveness ratios (e.g., \$20,700/ton HC and NO_x) when it is evaluated assuming all other red alert actions are in effect. However, both marginal cost and emission reduction effects of Action 15 are insignificant if all the other episode actions are in effect, i.e., if an emergency occurs, because working mothers would be home during an emergency and there would be no child care costs. Since all motor vehicle operations would be forbidden, the additional emission reduction effect of Action 15 would be zero.

Action 19 has relatively large cost/effectiveness ratios because curtailing activities at O'Hare affects a large number of travelers and the emission reductions are relatively small. Allowing flights to continue, but stopping all travel by motor vehicles to and from O'Hare* results in a cost of \$960,000 and emission reductions of 11.9 tons of HC and 11.1 tons of NO_x for a one-day episode. The cost/effectiveness ratios for this modification to Action 19 are \$80,708/ton HC, \$86,500/ton NO_x, and \$41,700/ton of HC and NO_x, i.e., it is less efficient.

The efficiency of the control actions that affect electricity consumption and power plant operations (i.e., Actions 3, 4, 5, 11, 12, 13, and 21) are relatively insensitive to the degree of control imposed. In all cases, the control of HC is relatively expensive, the control of NO_x is relatively inexpensive, and the control of the sum of HC and NO_x is relatively inexpensive. Furthermore, the cost/effectiveness ratios remain fairly constant with various combinations of load switching; fuel switching; buying of power; voltage reductions; reduced sales to large customers; and reduced consumption for air conditioning, advertising signs, lighting, and the like.

However, a number of issues should be kept in mind when analyzing the impacts of the actions that affect power plants. The cost and effectiveness estimates are based on a typical episode day. If electricity demand is higher than expected, the load switching options available to the power company will

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*This modification eliminates the diversion of through traffic, rescheduling, and shut-down/start-up costs, as well as reducing the passenger notification cost. The emission reductions would result from elimination of access traffic and travel to and from the airport.

be reduced. Furthermore, if natural gas or outside power is not available, the effectiveness of fuel swtiching and buying of power will be limited. These issues imply that the expected effectiveness of these actions is quite variable even though the efficiency is not.

Another aspect of controls affecting power plants is the fact that power plant stacks are relatively high. For non-reactive pollutants tall stacks are quite important. For precursors to ozone the effect of stack heights is not known. Finally, the costs of these actions are relatively high and most of them must be borne by Commonwealth Edison Company. This differs from other actions in which the cost burden is spread out over a number of firms or individuals.

All of the other actions (i.e., Actions 2, 9, 14, and 16) have relatively small emission reduction effects and intermediate cost/effectiveness ratios. Action 2 (review of action plans and inspection of control equipment) has no impact on emissions; however, it is the least expensive control action. Action 9 (curtailment of roadway repairs) is interesting because it is estimated that NO_x emissions will increase rather than decrease. Even with this effect, the cost/effectiveness ratio for the sum of HC and NO_x reductions is relatively low. Action 14 (curtailing government activities) is a middle-of-the-road action. Its cost, emission reduction effects, and cost/effectiveness ratios are all intermediate values. The major cost of the action involves the curtailment of government trucking operations, while the closing of government offices is relatively inexpensive. Again the assumptions on overtime affect these results. Action 16 (restrictions on the loading and unloading of organic material) has little effect on NO_x emissions but is relatively efficient in reducing HC emissions, provided it does not adversely affect petroleum refinery operations.

In summary, it is interesting to note that with few exceptions, the most efficient control strategies* are grouped in the yellow alert stage and the least efficient are grouped in the emergency stage. The other actions are in the red alert stage. Exceptions to this rule are the controls on fleet vehicles, Action 7 (primarily trucks), and the closing of schools, Action 15, which have relatively high cost/effectiveness ratios, and the

*Remember that the efficiencies are estimated assuming no other actions are in effect.

closing of larger parking facilities, Action 8, which has relatively low cost/effectiveness ratios. All of these activities are in the red alert episode stage. Controls on power plants become increasingly effective and costly as the episode stages advance even though the efficiency of these controls remains fairly constant.

Distributional Effects

Approximately 48.4% of the estimated annual social cost of the ozone episode regulation must be borne by the manufacturing sector (see Table 25.22); the bulk of this is overtime labor cost. The transportation and utility sectors must bear about 16.5% and 11.1% of the cost, respectively. The bulk of the transportation sector cost is also a result of overtime labor cost. The costs to utilities are primarily increased operating costs or reduced revenues to the electric power industry. The only other group to bear more than 10% of the annual social cost is the public; this cost is primarily a notification cost. However, not included in the cost to the public are the lost satisfaction costs due to delayed or foregone consumption (these are allocated to the retail, service, and other relevant sectors) and psychic and inconvenience costs (these are not estimated).

As in the analysis of other results, the role of the overtime adjustment cost is critical to the interpretation of the distributional effects of the ozone episode regulation. The importance of this assumption in this analysis cannot be overemphasized.

25.7 REFERENCES

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APPENDIX A:

ECONOMIC AND DEMOGRAPHIC DATA FOR THE CHICAGO SMSA AND ILLINOIS

Table A.1. Population of Selected Illinois Counties, 1950 - 1980

County	Population							
	1950	1960	1970	1971[a]	1972[b]	1973[c]	1974[c]	1980[d]
Cook	4,508,792	5,129,725	5,493,766	5,518,083	5,542,400	5,564,617	5,586,922	5,600,000
DuPage	154,599	313,459	490,822	502,961	515,100	517,165	519,238	580,000
Kane	150,388	208,246	251,005	255,953	260,900	261,946	262,996	280,000
Lake	179,097	293,656	382,638	386,119	389,600	391,162	392,730	440,000
McHenry	50,656	84,210	111,555	112,978	114,400	114,859	115,319	125,000
Will	134,336	191,617	247,825	255,013	262,200	263,251	264,306	290,000
Total Chicago SMSA 6-County Region	5,177,868	6,220,913	6,977,611	7,031,106	7,084,600	7,112,998	7,141,510	7,315,000
Grundy	19,217	22,350	26,535	27,118	27,700	27,811	27,923	32,000
Kankakee	73,524	92,063	97,250	98,375	99,500	99,899	100,299	110,000
Kendall	12,115	17,540	26,374	27,237	28,100	28,213	28,326	33,000
Total 9-County Chicago Region	5,282,724	6,352,866	7,127,770	7,183,835	7,239,900	7,263,921	7,298,058	7,490,000

Source: *Illinois State and Regional Economic Data Book*, Department of Business and Economic Development (BED), 1973.

[a]Average of 1970 and 1972 data; therefore, totals are not exact sums of numbers listed

[b]BED estimate.

[c]Exponential interpolation of 1972 and 1960 data (growth rate of 0.40 percent/year); therefore, totals are not exact sums of numbers listed.

[d]BED forecast.

Table A.2. Employment by Major Industry Groups in Northeastern Illinois -- 1971

Industry	Number of Employees, by County						
	Cook	DuPage	Kane	Lake	McHenry	Will	Total Chicago SMSA
Agriculture Service & Hunting	2,324	327	239	279	153	73	3,395
Mining	2,960	?[a]	96	17	183	301	?
Contract Construction	86,122	6,526	3,081	4,350	1,435	4,718	106,232
Manufacturing	762,604	26,509	34,848	38,003	13,349	25,175	900,488
Transportation & Utilities	186,543	6,165	3,549	3,868	1,030	6,835	207,990
Wholesale Trade	201,573	12,127	3,420	2,594	843	2,491	223,048
Retail Trade	367,390	29,277	16,141	19,338	5,066	10,966	448,178
Finance, Insurance & Real Estate	166,488	5,172	3,385	2,540	905	1,852	180,342
Service	400,974	24,457	13,913	15,444	3,147	9,277	467,212
Unclassified Establishments	6,363	?	207	308	94	83	?
Government							
Federal	58,610	1,218	1,591	8,578	173	2,749	72,919
State	12,610	147	3,092	255	73	1,658	17,835
Local	194,264	14,980	8,585	10,761	3,400	6,793	238,783
Total Chicago SMSA	2,448,825	127,528	92,147	106,335	29,851	72,971	2,877,657[b]

Source: *Suburban Factbook 1973*, Northeastern Illinois Planning Commission, Table II (Aug. 1973).

[a]Not disclosed.

[b]The total employment figures reported in the *Suburban Factbook* are incorrect. It seems that railroad employees were not included in the total. For example, the total employment in the Chicago SMSA is reported to be 2,841,659 rather than 2,877,657 which includes the 36,000 railroad employees. Some results of the study are based on the incorrect totals (e.g., on the 2,841,659 figure). Because the error was discovered late in the study, the error introduced is only about 1%, and none of the conclusions of the study are affected, we did not recalculate any of the affected estimates.

Table A.3. Manufacturing Employment in Chicago SMSA by SIC

SIC	Number of Employees 1971[a]	1972[b]	1973[b]	1974[c]
20	75,851	72,800	72,300	71,803
21	255	--	--	325[d]
22	3,269	--	--	3,269
23	20,764	20,300	20,900	20,654
24	6,699	5,000	5,700	5,800
25	16,288[a,d]	--	--	16,288
26	30,300	30,500	31,800	33,155
27	89,521	84,200	85,000	86,240
28	43,464	39,000	40,800	41,088
29	4,999	6,100	6,200	6,302
30	24,331[a,d]	27,500	30,200	33,165
31	5,524	--	--	5,524
32	17,846	19,900	21,200	22,585
33	61,055	59,200	60,900	60,385
34	97,723	110,200	114,200	118,345
35	102,188[a,d]	108,800	119,100	130,375
36	135,748	131,800	136,500	134,683
37	31,326	29,900	30,400	30,542
38	29,146[a,d]	--	--	29,146
39	28,611	30,100	31,000	31,927
TOTAL	824,908	840,000	873,000	881,601

[a] From *Suburban Factbook 1973*, Northern Illinois Planning Commission (1973).

[b] From *Annual Survey of Manufactures, 1973*, U.S. Department of Commerce, M73(AS)-6, p. 226.

[c] Estimated from 1971 to 1973 figures. If trend is in one direction, the change between 1972 and 1973 is assumed to occur between 1973 and 1974. If trend is not in one direction, 1974 is average of 1971 to 1973 data.

[d] *Illinois Manufacturers Directory*, 1972 through 1975, Manufacturer's News, Inc.

Table A.4. Statewide Summary Data

Type of Data	1960	1970	1971	1972	1973	1980
	Number of Persons					
Population	10,081,158	11,112,772	--	11,250,500[a]	--	11,600,000[b]
Employment (Non-Agriculture)	3,522,000	--	--	4,282,700	--	--
Mining	28,900	--	--	23,400	--	--
Contract Construction	166,400	--	--	180,300	--	--
Manufacturing	1,210,500	--	--	1,269,500	--	--
Transportation & Utilities	284,500	--	--	280,300	--	--
Wholesale Trade	217,200	--	--	273,200	--	--
Retail Trade	529,000	--	--	667,200	--	--
Financial, etc.	185,300	--	--	239,000	--	--
Service & Misc.	483,400	--	--	695,000	--	--
Government	416,900	--	--	654,800	--	--
	$\$10^6$					
Personal Income	25,663.9[c]	--	53,101.7	--	--	--
Gross State Product	33,843[d]	60,216	64,462	69,758	77,585[e]	--

Source: *Illinois State and Regional Data Book*, Department of Business and Economic Development (BED) (1973).

[a] BED estimate [b] BED forecast [c] 1959 [d] 1961 [e] Preliminary

Table A.5. Average Salaries: Metropolitan Areas (March 1975)

Occupation and Level	Monthly Salaries	
	Mean	Median
Attorneys I	$1,273	$1,250
Attorneys II	1,478	1,442
Attorneys III	1,881	1,868
Attorneys IV	2,350	2,300
Attorneys V	2,837	2,778
Attorneys VI	3,420	3,391
Job Analysts II	1,033	1,010
Job Analysts III	1,246	1,250
Job Analysts IV	1,542	1,540
Directors of Personnel I	1,400	1,416
Directors of Personnel II	1,674	1,599
Directors of Personnel III	2,097	2,043
Directors of Personnel IV	2,677	2,670
Engineers I	1,079	1,065
Engineers II	1,190	1,170
Engineers III	1,370	1,356
Engineers IV	1,630	1,610
Engineers V	1,876	1,855
Engineers VI	2,184	2,155
Engineers VII	2,430	2,374
Engineers VIII	2,848	2,765

Source: *National Survey of Professional, Administrative, Technical, and Clerical Pay*, Table 2, Average Salaries: Metropolitan Areas, U.S. Bureau of Labor Statistics, Washington, D.C. (March 1975).

Table A.6. Consumer Price Index for Urban Wage Earners and Clerical Workers U.S. City Average; All Items--Series A; (1967 = 100)

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Avg.
1967	98.6	98.7	98.9	99.1	99.4	99.7	100.2	100.5	100.7	101.0	101.3	101.6	100.0
1968	102.0	102.3	102.8	103.1	103.4	104.0	104.5	104.8	105.1	105.7	106.1	106.4	104.2
1969	106.7	107.1	108.0	108.7	109.0	109.7	110.2	110.7	111.2	111.6	112.2	112.9	109.8
1970	113.3	113.9	114.5	115.2	115.7	116.3	116.7	116.9	117.5	118.1	118.5	119.1	116.3
1971	119.2	119.4	119.8	120.2	120.8	121.5	121.8	122.1	122.2	122.4	122.6	123.1	121.3
1972	123.2	123.8	124.0	124.3	124.7	125.0	125.5	125.7	126.2	126.6	126.9	127.3	125.3
1973	127.7	128.6	129.8	130.7	131.5	132.4	132.7	135.1	135.5	136.6	137.6	138.5	133.1
1974	139.7	141.5	143.1	143.9	145.5	146.9	148.0	149.9	151.7	153.0	154.3	155.4	147.7
1975	156.1	157.2	157.8	158.6	159.3	160.6	162.3	162.8	163.6	164.6	165.6	166.3	161.2
1976	166.7	167.1	167.5	168.2	169.2	170.1	171.1	--[a]	--	--	--	--	168.6

Source: U.S. Department of Labor, Bureau of Labor Statistics.

[a]Not available for use in this study.

Table A.7. Delay Cost Factors for an Annual Cost of Capital of 10 Percent[a]

Maximum Delay (days)	Delay Cost Factors, by Minimum Delay (10^{-3})					
	1 Day	2 Days	3 Days	4 Days	5 Days	6 Days
2	0.13035	0.26071	--	--	--	--
3	0.26088	0.39131	0.52132	--	--	--
4	0.39138	0.52183	0.65210	0.78158	--	--
5	0.52185	0.65232	0.78265	0.91267	0.10424	--
6	0.65231	0.78277	0.91313	1.0433	1.1735	1.3036
7	0.78274	0.91319	1.0436	1.1738	1.3041	1.4345
8	0.91315	1.0436	1.1740	1.3043	1.4346	1.5650
9	1.0435	1.1740	1.3044	1.4346	1.5650	1.6954
10	1.1739	1.3043	1.4347	1.5650	1.6953	1.8258
11	1.3042	1.4347	1.5650	1.6953	1.8257	1.9561
12	1.4346	1.5650	1.6953	1.8256	1.9560	2.0863
13	1.5648	1.6953	1.8256	1.9559	2.0862	2.2166
14	1.6951	1.8255	1.9559	2.0862	2.2165	2.3468
21	2.6064	2.7367	2.8670	2.9972	3.1275	3.2578
28	3.5166	3.6468	3.7770	3.9072	4.0374	4.1675
91	11.658	11.788	11.917	12.047	12.176	12.306
182	33.263	23.391	23.520	23.648	23.777	23.905
365	46.052	46.178	46.305	46.431	46.558	46.684

[a] r = 0.10 is equivalent to i = 0.00026116

APPENDIX B. POWER PLANT SIMULATION MODEL

B.1 ESTIMATING POWER PLANT OPERATING COSTS

To estimate the cost of the actions that affect power plant operations, it was necessary to develop a method of estimating the kilowatt hours of electricity generated by each power plant. Power stations are first divided into three types of plants: nuclear, non-peaking fossil (or simply fossil), and fast-start peaking (or simply peaking) units. Each type of plant has several distinctive characteristics. The nuclear plants have the lowest operating and average costs; however, nuclear plants have very high start-up and shut-down costs, making it expensive to regulate the output to the hourly demand. Thus, nuclear plants are employed for base load and produce a fairly constant flow of electricity.* Fossil plants have higher operating and average costs than nuclear plants, but these costs are lower than those of peaking units. Start-up and shut-down costs are substantial, yet it is practical for fossil plants to generate at a load below capacity. (Minimum loads at which each plant can economically operate were supplied by Commonwealth Edison [Ref. 1]). Fossil plants are used both as base load and cycling plants. Peaking plants, while expensive to operate, can be brought on-line very quickly; they are employed during the peak demand hours of the day.

From these characteristics, the following decision rules were developed to estimate the power supplied by each plant in the Commonwealth Edison system. First, nuclear plants will supply 3000 MW of power each hour, or about the equivalent of half of the Dresden plant's capacity, plus one-fourth of the Quad Cities plant's capacity, plus the total capacity of the Zion plant. The power supplied will be assumed not to vary according to the hourly demand. Fossil plants will be assumed to supply up to 65% of the total hourly demand, with peaking units supplying the remainder if needed.

For example, if the hourly demand is 9,143 MW, then 3,000 MW would be supplied by the nuclear plants, 9,143 • 0.65 = 5,943 MW by the fossil plants, and the remaining 200 MW by peakers. If the hourly demand is 8,516 MW, then

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*Due to cooling water restrictions, much of the present nuclear capacity is unavailable on an average summer day [Ref. 3]. (References are listed in Sec. B.3.).

3,000 MW would be supplied by the nuclear plants and 8,516 - 3,000 = 5,516 MW (5,516 < 0.65 • 8,516 = 5,535) by the fossil plants, and none by peakers. Table B.1 provides additional examples.

Fossil plants will be assumed to be brought on-line to at least their minimum load, and raised to their capacity in ascending order of their average operating costs until the demand is satisfied.* All fossil plants will not

Table B.1. Assumed Unregulated Demand and Supply for Electrical Power during Ozone Alert

Hour	Hourly Demand	MW Supplied by Type of Plant		
		Nuclear	Fossil	Peaking
1	8,516	3,000	5,516	0
2	8,141	3,000	5,141	0
3	7,900	3,000	4,900	0
4	7,823	3,000	4,823	0
5	7,846	3,000	4,846	0
6	7,945	3,000	4,945	0
7	8,312	3,000	5,312	0
8	9,143	3,000	5,943	200
9	9,943	3,000	6,463	480
10	10,572	3,000	6,872	700
11	10,895	3,000	7,082	813
12	11,109	3,000	7,221	888
13	11,223	3,000	7,295	928
14	11,388	3,000	7,402	986
15	11,465	3,000	7,453	1,013
16	11,436	3,000	7,433	1,002
17	11,500	3,000	7,475	1,025
18	11,480	3,000	7,462	1,018
19	11,354	3,000	7,380	974
20	11,143	3,000	7,243	900
21	11,010	3,000	7,157	854
22	10,960	3,000	7,124	836
23	10,501	3,000	6,825	675
24	9,712	3,000	6,313	399
TOTAL	241,318	72,000	155,626	13,692

*Average operating costs, net capability, and minimum load information was supplied by Commonwealth Edison Company [Ref. 1].

necessarily operate. It is assumed that Edison is able to estimate with some accuracy the upcoming demand and prepare to meet a demand greater than is actually desired. These decision rules, though much less complicated than those actually used by Edison, do approximate the operation of the system with sufficient accuracy to estimate Edison's operating costs.

Peak demand during an episode is assumed to be 11,500 MW. This is somewhat below the 1975 annual peak, yet above the average summer day's peak, and is, therefore reasonable. The hourly demand was estimated as a percentage of the peak. The percentage data were estimated from the five-day average hourly demand for the period of June 7-11, 1976 [Ref. 1].

Table B.1 shows the hourly demand for the assumed "normal unregulated ozone day" or "typical episode day." Also shown is the power supplied by nuclear, fossil, and peaking plants.

Table B.2 lists the plant outputs that would satisfy the demand according to the decision rules described above; it also presents the estimated operating costs under the assumptions of the model. These tables provide the basis for comparison with the regulated situation.

B.2 ESTIMATING POWER PLANT EMISSIONS

Emissions from the Chicago area power plants are estimated by multiplying the MWh output of each power plant unit by an appropriate emission factor. Table B.3 provides the HC and NO_x emission factors for the fossil plants during the assumed normal operating conditions and when the fuel switching option is employed. Table B.4 lists the emission factors for the peaking units. The model does not allocate peaking unit generation to the various peaking units; therefore, the average emission factors are used in the model. Since about 92% of the peaking unit capacity is in the Chicago SMSA, only 92% of the peaking unit emissions is allocated to the Chicago SMSA.

The emission factors in these tables were estimated as follows:

$$E = H \cdot \overline{E}/(2000 \cdot T) \tag{B.1}$$

where:

Table B.2. Plant Output and Operating Costs during Assumed Unregulated Ozone Alert[a]

Power Plant	Output (MWh/Day)	Cost ($/Day)
Dresden	23,520	85,829
Quad Cities	9,600	36,576
Zion	38,880	156,298
Crawford	9,191	110,959
Dixon	1,320	16,546
Fisk	6,643	84,685
Joliet	26,261	308,937
Kincaid	25,398	150,226
Powerton	39,816	223,365
Ridgeland	0	0
Sabrooke	0	0
State Line	13,912	169,913
Waukegan	16,622	124,316
Will County	16,464	205,536
Peaking Units	13,692	709,588
TOTAL	241,318	2,382,770

[a]Costs are in 1976 dollars.

$E \equiv$ the emission factor in tons of pollutant/kWh;

$H \equiv$ heat rate of the power plant unit in Btu/kWh;

$\overline{E} \equiv$ emission factor from Ref. 2 in lbs/ton coal, lbs/10^3 gallons oil, or lbs/10^6 ft^3 of natural gas;

$T \equiv$ heat content of the fuel used in Btu/ton coal, Btu/10^3 gallons oil, or Btu/10^6 ft^3 natural gas; and

The constant 1/2000 converts pounds to tons.

Table B.5 summarizes the values of $\overline{E}$ and T used in Eq. B.1. The values of H are found in Table B.3 and B.4. For example, the emission factors for Joliet Unit 8 under normal operating conditions are:

Coal: $(11{,}140 \cdot 0.3)/(21 \cdot 10^6 \cdot 2000) = 0.0796 \cdot 10^{-6}$ tons HC/kWh

Coal: $(11{,}140 \cdot 18)/(21 \cdot 10^6 \cdot 2000) = 4.774 \cdot 10^{-6}$ ton NO_x/kWh

N. Gas: $(9{,}600 \cdot 1.0)/(1{,}050 \cdot 10^6 \cdot 2000) = 0.0046 \cdot 10^{-6}$ ton HC/kWh

N. Gas: $(9{,}600 \cdot 600)/(1{,}050 \cdot 10^6 \cdot 2000) = 2.743 \cdot 10^{-6}$ ton NO_x/kWh

Table B.3. Emission Factors for Fossil Fuel Plants in the Chicago SMSA

Plant, Unit Number	Normal Operating Conditions				With Fuel Switching			
	Fuel	Heat Rate[a] (Btu/kWh)	HC Emission Factor (10^{-6} tons/kWh)	NO_x Emission Factor (10^{-6} tons/kWh)	Fuel	Heat Rate[a] (Btu/kWh)	HC Emission Factor (10^{-6} tons/kWh)	NO_x Emission Factor (10^{-6} tons/kWh)
Crawford, #6	Coal	23,090	0.1649	9.90	N. Gas	15,000	0.0071	4.29
Crawford, #7	Coal	9,470	0.0676	4.06	N. Gas	9,455	0.0045	2.70
Crawford, #8	Coal	10,450	0.0746	4.48	N. Gas	9,700	0.0046	2.77
Fisk, #18	Coal	15,320	0.1094	6.56	Coal	15,320	0.1094	6.56
Fisk, #19	Coal	11,890	0.0849	5.09	N. Gas	9,433	0.0045	2.70
Joliet, #5	Coal	10,514	0.0751	4.51	Coal	10,514	0.0751	4.51
Joliet, #6	Coal	11,040	0.0789	4.73	Coal	11,040	0.0789	4.73
Joliet, #7	Coal	10,920	0.0780	4.68	N. Gas	9,600	0.0046	2.74
Joliet, #8	Coal	11,140	0.0796	4.77	N. Gas	9,600	0.0046	2.74
Ridgeland, #1	Oil	12,030	0.0802	4.21	N. Gas	9,259	0.0044	2.65
Ridgeland, #2	Oil	12,300	0.0820	4.31	N. Gas	9,124	0.0043	2.61
Ridgeland, #3	Oil	10,520	0.0701	3.68	N. Gas	9,124	0.0043	2.61
Ridgeland, #4	Oil	10,850	0.0723	3.80	N. Gas	9,398	0.0045	2.68
State Line, #1	Coal	17,540	0.1253	7.52	Coal	17,540	0.1253	7.52
State Line, #2	Coal	12,970	0.0926	5.56	Coal	12,970	0.0926	5.56
State Line, #3	Coal	9,560	0.0683	4.10	Coal	9,560	0.0683	4.10
State Line, #4	Coal	9,840	0.0703	4.22	Coal	9,840	0.0703	4.22
Waukegan, #5	Coal	13,620	0.0973	5.84	N. Gas	13,109	0.0062	3.75
Waukegan, #6	Coal	12,120	0.0866	5.19	N. Gas	8,319	0.0040	2.38
Waukegan, #7	Coal	10,510	0.0751	4.50	N. Gas	7,786	0.0037	2.22
Waukegan, #8	Coal	9,640	0.0689	4.13	N. Gas	7,583	0.0036	2.17
Will County, #1	Coal	11,360	0.0811	4.87	Coal	11,360	0.0811	4.87
Will County, #2	Coal	10,840	0.0774	4.65	Coal	10,840	0.0774	4.65
Will County, #3	Coal	10,180	0.0727	4.36	Coal	10,180	0.0727	4.36
Will County, #4	Coal	10,170	0.0726	4.36	Coal	10,170	0.0726	4.36

[a]From Ref. 1.

Table B.4. Emission Factors for Peaking Units

Power Plant	Fuel	Heat Rate[a] (Btu/kWh)	HC Emission Factors[b] (10^{-6} tons/kWh)	NO_x Emission Factors[b] (10^{-6} tons/kWh)
Calumet	Oil	17,510	0.188	3.752
Crawford	Oil	17,460	0.187	3.741
Crawford	Gas	17,460	0.008	4.989
Fisk	JP4[c]	16,370	0.175	3.508
Joliet	Oil	17,470	0.187	3.744
Waukegan	JP4	17,470	0.187	3.744
Waukegan	Gas	17,470	0.008	4.991
Bloom	Oil	18,830	0.202	4.035
Bloom	Gas	18,830	0.009	5.380
Electric Junction	Oil	18,800	0.201	4.029
Electric Junction	Gas	18,800	0.009	5.371
Lombard	JP4	14,410	0.154	3.088
Lombard	Gas	14,410	0.007	4.117
Weighted Average	--	--	0.144	4.033

[a]From Ref. 1.

[b]Based on emission factors in Ref. 2.

[c]Assumed the same as oil.

Table B.5. Data Used to Calculate Emission Factors

Fuel	HC Emission Factor[a] (lbs/unit fuel)[b]	NO_x Emission Factor[a] (lbs/unit fuel)	Heat Content (Btu/unit fuel)
Fossil Plants			
Coal	0.3	18	$21 \cdot 10^6$
Oil	2.0	105	$150 \cdot 10^6$
Natural Gas	1.0	600	$1{,}050 \cdot 10^6$
Peakers			
Oil/JP4	3.0	60	$140 \cdot 10^6$
Natural Gas	1.0	600	$1{,}050 \cdot 10^6$

[a]From Ref. 2

[b]Unit fuel ≡ ton of coal, 10^3 gallons of oil, and $10^6 ft^3$ of natural gas.

For the gas peaking unit at the Crawford plant, the emission factors are:

$$(17{,}460 \cdot 1.0)/(1{,}050 \cdot 10^6 \cdot 2000) = 0.0083 \cdot 10^{-6} \text{ tons HC/kWh, and}$$
$$(17{,}460 \cdot 600)/(1{,}050 \cdot 10^6 \cdot 2000) = 4.989 \cdot 10^{-6} \text{ tons } NO_x\text{/kWh.}$$

The emission factors used in the power plant simulation model were based on data provided in Ref. 2. Commonwealth Edison provided NO_x emission rates for each power plant unit based on actual "tests, except for those units having cyclone firing. Emission rates of 1.1 to 1.2 lbs/10^6 Btu were generally assigned to cyclone units on the basis of limited test data available from other research" [Ref. 1]. Seven of the 25 units have cyclone firing. For the other coal fired units, the emission rates ranged between 0.3 and 0.83 lbs $NO_x/10^6$ Btu. The oil plant emission rates are 0.6 lbs/10^6 Btu. Based on the Commonwealth Edison data, the NO_x emission factors would range from $1.52 \cdot 10^{-6}$ to $7.02 \cdot 10^{-6}$ tons NO_x/kWh for the non-cyclone fired plants, $5.78 \cdot 10^{-6}$ to $8.43 \cdot 10^{-6}$ tons NO_x/kWh for the cyclone fired plants, and $3.16 \cdot 10^{-6}$ to $3.69 \cdot 10^{-6}$ tons NO_x/kWh for the oil fired plant. These compare to ranges of $4.06 \cdot 10^{-6}$ to $9.90 \cdot 10^{-6}$, $4.22 \cdot 10^{-6}$ to $6.56 \cdot 10^{-6}$, and $3.68 \cdot 10^{-6}$ to $4.31 \cdot 10^{-6}$ tons NO_x/kWh, respectively, using the data in Ref. 2. The emission factors used in the study tend to overestimate emissions from coal non-cyclone fired units, underestimate them for the coal cyclone fired units, and slightly overestimate them for the oil fired units, relative to the Commonwealth Edison test data.

For the peakers, the weighted average NO_x emission factor using the Commonwealth Edison data is $4.842 \cdot 10^{-6}$ tons NO_x/kWh as compared to the slightly lower weighted average emission factor used in the study of 4.033 $\cdot 10^{-6}$ tons NO_x/kWh.

The emission factors based on Ref. 2 were used because they provide consistent estimates of NO_x emissions for coal and natural gas; this consistency is required to estimate the emission reduction effects of fuel switching. Furthermore, HC emissions also could be estimated, which was not possible with the Commonwealth Edison data.

B.3 REFERENCES

1. Fancher, J., Commonwealth Edison Company, personal communications (1976).

2. *Compilation of Air Pollution Emission Factors*, U.S. EPA, AP-42 (1975).

3. Giese, R.F., Argonne National Laboratory, personal communications (1976).

APPENDIX C. ESTIMATING THE VALUE OF OUTPUT

The value of output associated with particular industries is of great importance to the study. Throughout the study, the effects of the regulations on particular industries or industrial sectors must be evaluated. The question one therefore attempts to answer is: What is the social cost of the regulation? Knowledge of the demand and cost schedules for each market would ideally be required. However, such an approach is impractical. As a surrogate, the reduction in output as measured by factor income is employed. Factor income for manufacturing industries is measured by the value added by manufacture. Non-manufacturing factor income is estimated as described in Sec. C.2.

C.1 VALUE ADDED BY MANUFACTURE

Value added by manufacture is a measure of the relative economic output of a manufacturing industry; it is equivalent to the factor income flowing from the industry. Value added by manufacture is:

> ...derived by subtracting the total cost of materials (including materials, supplies, fuels, electrical energy, cost of resales, and miscellaneous receipts) from the value of shipments (including resales) and other receipts, and adjusting the resulting amount by the net change in finished products and work-in-process inventories between the beginning and end of the year [Ref. 2].*

The remainder is the return to the factors of production (labor, capital, etc.) employed during the year in the industry.

Value added by manufacture is estimated each year by the Bureau of the Census for all two-digit SIC industries. Table C.1 summarizes the statistics for the U.S., Illinois, and the Chicago SMSA. The data omitted are withheld by the Bureau where so few firms operate within the industry for the geographic area that to present the statistic would disclose information about individual companies. Data for 1974 have not yet been published.

Data omitted to avoid disclosing figures for individual companies are estimated by subtracting values given for all disclosed industries from total manufacturing and assuming that the undisclosed values are proportional to the state or national figures. For instance, value added for manufacturing in

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*References are listed in Sec. C.3.

Table C.1. Value Added by Manufacture, 1973

Industry and SIC Code	1973 Value Added ($\$10^6$)		
	U.S.[a]	Illinois[b]	Chicago SMSA[b]
Food and Kindred Products (20)	39,692.7	3,236.7	2,092.0
Tobacco Manufactures (21)	2,900.1	--[c]	--[c]
Textile Mill Products (22)	13,016.8	83.5	--[c]
Apparel and Other Textile Products (23)	14,648.2	368.7	283.7
Lumber and Wood Products (24)	12,357.2	175.4	--[c]
Furniture and Fixtures (25)	6,735.5	431.7	--[c]
Paper and Allied Products (26)	15,166.0	861.8	665.1
Printing and Publishing (27)	21,871.2	2,361.7	1,958.2
Chemicals and Allied Products (28)	36,239.4	2,408.0	1,756.0
Petroleum and Coal Products (29)	7,740.2	660.5	384.1
Rubber and Plastics Products (30)	13,439.6	768.0	489.9
Leather and Leather Products (31)	2,962.0	--[c]	--[c]
Stone, Clay, and Glass Products (32)	13,801.0	895.5	445.6
Primary Metal Industries (33)	28,614.1	2,314.0	1,333.3
Fabricated Metal Products (34)	30,573.4	3,218.1	2,333.3
Machinery, except Electrical (35)	44,559.0	4,911.4	2,531.0
Electrical Equipment and Supplies (36)	34,984.2	3,590.8	2,841.1
Transportation Equipment (37)	45,684.9	1,253.3	858.8
Instruments and Related Products (38)	12,224.3	1,030.4	--[c]
Miscellaneous Manufacturing Industries (39)	7,166.3	612.4	514.5
Total Manufacturing	404,376.2	29,356.7	19,938.8

[a]Source: *Annual Survey of Manufactures: 1973*, U.S. Department of Commerce, M73 (AS)-1 (1976).

[b]Source: *Annual Survey of Manufactures: 1973*, U.S. Department of Commerce, M73 (AS)-6 (1976).

[c]Withheld to avoid disclosing figures for individual companies.

SICs 21 and 31 for Illinois are not disclosed, but all two-digit industry values are given for the nation. Subtracting the value added in Illinois for SICs 20, 22-30, and 32-39 from the state's total manufacturing value added leaves \$174.8 million as the sum for SICs 21 and 31. The national value added sum for SICs 21 and 31 is \$5,862.1 million. By multiplying the national value for each of the two undisclosed SICs by the ratio of the Illinois sum for SICs 21 and 31 to the national sum for SICs 21 and 31, the Illinois values can be estimated:

SIC 21: $\$2,900.1 \cdot 10^6 \cdot (174.8/5,862.1) = \$86.5 \cdot 10^6$

SIC 31: $\$2,962.0 \cdot 10^6 \cdot (174.8/5,862.1) = \$88.3 \cdot 10^6$

The same process is used to allocate the undisclosed values for the Chicago SMSA from the Illinois data.

The 1973 values and estimates for the Chicago SMSA are adjusted to account for changes in industrial production between 1973 and 1974. Since no Chicago or Illinois indices of manufacturing output are available, the National Federal Reserve Board's Product Index for Manufacturing is used. This index is 129.8 for 1973 and 129.4 for 1974 [Ref. 5]. For example, the 1973 value added by manufacture in SIC 20 for the Chicago SMSA is \$2,092.0 million. Multiplying this value by the ratio of the 1974 index to the 1973 index, the 1974 value added by manufacture in SIC 20 is estimated as: $\$2,092.0 \cdot 10^6 \cdot (129.4/129.8) = \$2,085.6 \cdot 10^6$. Table C.2 summarizes the 1974 estimates for the two-digit manufacturing industries.

C.2 FACTOR INCOME TO NON-MANUFACTURING INDUSTRIES

Non-manufacturing industries have no equivalent measure to value added by manufacture. However, the factor income to non-manufacturing industries can be estimated if one is willing to accept several simplifying assumptions. The procedure and assumptions which have been used are described below.

In the estimation of factor income, one begins with personal income, which is the current income received by persons from all sources, inclusive of transfers from government and business, but exclusive of transfers among persons. Personal income is measured on a before-tax basis, and is the sum of wages and salary disbursements, other labor income, proprietors' income, rental income of persons, dividends, personal interest income, and transfer payments, less personal contributions to social insurance [Ref. 1]. To arrive at total factor income, one must add personal contributions to social insurance and undistributed corporate profits and subtract transfer payments. Personal contributions to social insurance and transfer payments for Illinois are published [Ref. 7]. Undistributed corporate profits (retained earnings) for Illinois must be estimated.

To estimate undistributed corporate profits for Illinois, it is assumed that the ratio of undistributed corporate profits in Illinois to undistributed

Table C.2. Estimated Valued Added by Manufacture for Chicago SMSA, 1974

Industry and SIC Code	Estimated 1974 Value Added ($\$10^6$)
Food and Kindred Products (20)	2,085.6
Tobacco Manufactures (21)	66.1
Textile Mill Products (22)	63.8
Apparel and Other Textile Products (23)	282.8
Lumber and Wood Products (24)	134.0
Furniture and Fixtures (25)	329.7
Paper and Allied Products (26)	663.1
Printing and Publishing (27)	1,952.2
Chemicals and Allied Products (28)	1,750.6
Petroleum and Coal Products (29)	382.9
Rubber and Plastics Products (30)	488.4
Leather and Leather Products (31)	67.4
Stone, Clay, and Glass Products (32)	444.2
Primary Metal Industries (33)	1,329.2
Fabricated Metal Products (34)	2,326.1
Machinery, except Electrical (35)	2,523.2
Electrical Equipment and Supplies (36)	2,832.3
Transportation Equipment (37)	856.2
Instruments and Related Products (38)	786.9
Miscellaneous Manufacturing Industries (39)	512.9
Total Manufacturing	19,877.6

corporate profits for the nation is equal to the ratio of dividends, interest, and rents for Illinois to dividends, interest, and rents for the nation. The values for dividends, interest, and rents are given in Table C.3. Undistributed corporate profits for Illinois are thus estimated as: $\$44,430 \cdot 10^6 \cdot (10,137/168,022) = \$2,681 \cdot 10^6$.

Therefore, factor income in Illinois is estimated to be $68,280 million, as summarized below:

Personal Income in Illinois	$\$69,950 \cdot 10^6$
+ Personal Contributions to Social Insurance	$+\ 2,778 \cdot 10^6$
+ Undistributed Corporate Profits	$+\ 2,681 \cdot 10^6$
- Transfer Payments	$-\ 7,129 \cdot 10^6$
= Factor Income in Illinois	$\$68,280 \cdot 10^6$

Table C.3. Personal Income by Major Sources, 1974[a]

Income Source	1974 Personal Income ($\$10^6$) U.S.	Illinois
Personal Income	1,159,478	69,950
Wages and Salary Disbursements	758,060	47,060
Other Labor Income	52,307	3,212
Proprietors' Income	89,533	4,911
Dividends, Interest, and Rents	168,022	10,137
Transfer Payments	139,055	7,129
Personal Contributions to Social Insurance	47,499	2,778
Residents' Adjustments	--	279

[a] Source: *Survey of Current Business, 56*(8), U.S. Department of Commerce (Aug. 1976).

Factor income in Illinois from non-manufacturing industries is estimated by subtracting the value added by manufacture from the total factor income in Illinois. Since the value added by manufacture in Illinois for 1974 is not available, an estimate must be made from the 1973 value decreased by the Federal Reserve Board Product Index for Manufacturing for 1973 and 1974, as was done in estimating the 1974 value added by manufacture for the Chicago SMSA. The index is 129.8 for 1973 and 129.4 for 1974 [Ref. 5]. Applying the same ratio equation as discussed above, the value added by manufacture in 1974 is estimated to be $29,266.2 million. Subtracting the value added by manufacture in Illinois from total factor income, factor income in Illinois from non-manufacturing industries is $39,013.8 million.

Factor income for non-manufacturing two-digit SIC industries can be estimated for the Chicago SMSA from the taxable payrolls data [Ref. 4] published by the Bureau of the Census by making two rather broad assumptions. First, it is assumed that all non-manufacturing industries employ the factors of production (labor, capital, etc.) in the same proportion. Second, it is assumed that income to labor is directly related to taxable payrolls when an adjustment is made for high income earners.

The first assumption seems reasonable for most non-manufacturing industries. Retail and wholesale trade, contract construction, services, and finance are all very labor intensive industries. By assuming that the production functions for these industries are the same, one would not be far wrong. Mining

and agriculture are much more capital intensive than the other non-manufacturing industries. However, one finds that very little mining takes place within the SMSA and agriculture is not directly affected by the regulations. Thus, the error cannot be substantial.

The second assumption is much less reliable. Taxable payrolls are defined as the taxable wages paid for covered employment during the January-March quarter. Taxable wages for covered employment include all payments up to the first $7,800 paid to any one employee by any one employer during the year, including the cash value of payments in kind. Generally, first quarter taxable wages closely approximate total wages as all payments in the first quarter would be taxable unless the employee is paid at a rate of more than $31,200 per year [Ref. 4]. An adjustment must be made for higher income employees to estimate total labor income. If such high income employees are equally distributed throughout the state, the adjustments for the state and Chicago SMSA would cancel out in a proportionality relationship, i.e., the ratio of taxable payrolls for industry i in the Chicago SMSA to taxable payrolls for industry i in the state equals the ratio of non-manufacturing factor income in the Chicago SMSA to non-manufacturing factor income in the state. However, proportionately more high income wage-earners reside in the Chicago SMSA than in the state as a whole. In 1969, the percentage of families with annual incomes over $25,000 in the state was 5.8 while for the Chicago SMSA it was 7.3 [Ref. 3]. An adjustment factor of 20% seems reasonable and was used in the proportionality relationship, i.e.:

$$1.2 \cdot P_{ci}/P_{si} = I_{ci}/I_{si} \tag{C.1}$$

where:

P_{ci} ≡ taxable payrolls in the Chicago SMSA in industry i,
P_{si} ≡ taxable payrolls in Illinois in industry i,
I_{ci} ≡ factor income in the Chicago SMSA in industry i, and
I_{si} ≡ factor income in Illinois in industry i.

From the assumption that all non-manufacturing industries employ the factors of production in the same proportion, it follows that the ratio of the factor income for individual industries to taxable payrolls in each industry is equal to the ratio of factor income in all non-manufacturing industries to taxable payrolls in all non-manufacturing industries. That is:

$$I_{si}/P_{si} = I_{snm}/P_{snm} \tag{C.2}$$

where:

I_{snm} ≡ non-manufacturing factor income in Illinois,
P_{snm} ≡ non-manufacturing taxable payrolls in Illinois, and
I_{si} and P_{si} are defined as in Eq. C.1.

Combining Eqs. C.1 and C.2 and solving for factor income in the Chicago SMSA in industry i, one finds that:

$$I_{ci} = 1.2 \cdot P_{ci} \cdot I_{snm}/P_{snm} \tag{C.3}$$

Equation C.3 is used to estimate the factor incomes for non-manufacturing industries as presented in Table C.4.

C.3 REFERENCES

1. *Business Statistics, 1973,* Vol. 1, U.S. Department of Commerce (1973).

2. *Census of Manufactures: Illinois, 1972,* U.S. Department of Commerce, Bureau of the Census (1975).

3. *County and City Data Book 1972,* U.S. Department of Commerce, Bureau of the Census (1973).

4. *County Business Patterns 1973: Illinois,* U.S. Department of Commerce, Bureau of the Census (1974).

5. Greenfield, Ella, Federal Reserve Board, personal communication (Sept. 15, 1976).

6. *Survey of Current Business, 56*(7), U.S. Department of Commerce, Bureau of Economic Analysis (July 1976).

7. *Survey of Current Business, 56*(8), U.S. Department of Commerce, Bureau of Economic Analysis (Aug. 1976).

Table C.4. Taxable Payrolls and Factor Income by Industry

Industry and SIC Code	Taxable Payroll for Chicago SMSA, 1973[a] ($\$10^3$)	Estimated Factor Income for Chicago SMSA, 1974 ($\$10^3$)
Agriculture Services and Hunting (07)	6,594	60,698
Forestry (08)	39	359
Fisheries (09)	72	663
Metal Mining (10)	--[b]	--
Bituminous Coal and Lignite Mining (12)	1,261	11,608
Oil and Gas Extraction (13)	419	3,857
Nonmetallic Minerals, except Fuels (14)	3,314	30,505
General Building Contractors (15)	88,718	816,649
Heavy Construction Contractors (16)	37,653	346,596
Special Trade Contractors (17)	251,402	2,314,155
Local and Interurban Passenger Transit (41)	54,100	497,991
Trucking and Warehousing (42)	176,580	1,625,419
Water Transportation (44)	5,733	52,772
Transportation by Air (45)	80,918	744,850
Pipe Line Transportation (46)	--[b]	--
Transportation Services (47)	16,203	149,149
Communication (48)	136,683	1,258,167
Electric, Gas, and Sanitary Services (49)	77,257	711,151
Wholesale Trade (50 & 51)	624,889	5,752,103
Building Materials and Farm Equipment (52)	24,311	223,783
General Merchandise (53)	172,224	1,585,322
Food Stores (54)	82,851	762,643
Automotive Dealers and Service Stations (55)	105,550	971,588
Apparel and Accessory Stores (56)	47,497	437,210
Furniture and Home Furnishings Stores (57)	--[b]	--
Eating and Drinking Places (58)	94,389	868,851
Miscellaneous Retail Stores (59)	63,226	581,995
Banking (60)	105,049	966,976
Credit Agencies other than Banks (61)	39,173	360,587
Security, Commodity Brokers, and Services (62)	39,669	365,153
Insurance Carriers (63)	118,380	1,089,689
Insurance Agents, Brokers, & Service (64)	34,311	315,833
Real Estate (65)	82,700	761,254
Combined Real Estate, Insurance, etc. (66)	2,503	23,040
Holding and other Investment Companies (67)	--[b]	--
Hotels and other Lodging Places (70)	34,373	316,403
Personal Services (72)	48,429	445,789
Miscellaneous Business Services (73)	185,053	1,703,413
Auto Repair, Services, & Garages (75)	30,715	282,732
Miscellaneous Repair Services (76)	20,722	190,746
Motion Pictures (78)	9,580	88,184
Amusement and Recreation Services (79)	29,196	268,749
Medical and other Health Services (80)	220,970	2,034,029
Legal Services (81)	31,067	285,972
Educational Services (82)	98,188	903,821
Museums, Botanical and Zoological Gardens (84)	3,723	34,270
Nonprofit Membership Organizations (86)	88,527	814,891
Miscellaneous Services (89)	112,312	1,033,832
Other Non-Manufacturing	423,452	3,897,876

[a]From Ref. 4.

[b]Withheld to avoid disclosing figures for individual companies.

APPENDIX D: ESTIMATING RADIO AND TV ANNOUNCEMENT COSTS

The cost of radio and TV announcements is approximated by the average value of the air time used to make them. The average value of a minute of air time can be estimated by dividing the revenues of a radio station by its total air time. However, revenue data are not available. Therefore, it is assumed that the average value of a minute of air time is equal to the *lowest* advertising rate at each station as reported in *Spot Radio Rates and Data* [Ref. 1] and *Spot Television Rates and Data* [Ref. 2].

For the 59 radio stations in the Chicago SMSA, the average minimum advertising rate in 1976 is $19.50/min. Adjusting this for 1974 prices gives a cost of $17.10/min.* If radio announcements are assumed to occur on the average of once an hour from 6 a.m. through midnight, i.e., an average of 18 announcements per station per day, and each announcement is assumed to be 10 seconds long, then the radio notification cost would be: $C = 59 \cdot 18 \cdot 10 \cdot 17.1/60 = \$3{,}024/\text{day}$.

For the seven television stations in the Chicago SMSA, the average minimum advertising rate in 1976 is $205/min. Adjusting this for 1974 prices gives a cost of $180/min.* If television announcements are assumed to occur on the average of once an hour from 6 a.m. through midnight, i.e., an average of 18 announcements per station per day, and each announcement is assumed to be 10 seconds long, then the television notification cost would be: $\overline{C} = 7 \cdot 18 \cdot 10 \cdot 180/60 = \$3{,}780/\text{day}$.

The total cost of radio and TV announcements is therefore $3,024 + $3,780 = $6,804/day.

REFERENCES

1. *Spot Radio Rates and Data,* Standard Rates and Data Service, Inc., Skokie, Ill. (May 1, 1976).

2. *Spot Television Rates and Data,* Standard Rates and Data Service, Inc., Skokie, Ill. (1976).

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*See Table A.6 for Consumer Price Index figures.

APPENDIX E: METHODOLOGY FOR ESTIMATING MOTOR VEHICLE EMISSIONS

In this section the procedure for estimating nitrogen oxide (NO_x) and hydrocarbon (HC) emissions from motor vehicles is explained. Emission reductions due to episode controls are determined within the same framework.

E.1 MOTOR VEHICLE CLASSES

The transportation system consists of numerous classes of vehicles which have different pollutant emission rates and travel characteristics. Since emission rates vary considerably among these classes, emission calculations must be made for each class separately and then summed to obtain the total. In this appendix, only roadway vehicles are considered; other vehicles are discussed in the text as they relate to the individual actions.

Motor vehicles can be grouped into the following broad classes based upon their emission characteristics:

- Low-annual-mileage automobiles (such as private passenger cars and some fleet autos),
- High-annual-mileage automobiles (such as police cars and taxis),
- Light duty gasoline-powered trucks less than 8500 lbs gross vehicle weight (GVW),
- Heavy duty gasoline-powered trucks greater than 8500 lbs GVW,
- Heavy duty diesel-powered trucks,
- Transit buses,
- School buses,
- Buses for commercial use, and
- Motorcycles and motorbikes.

The rationale behind the above breakdown is as follows. High-annual-mileage autos tend to be later model vehicles than low-annual-mileage autos; late model cars exhibit lower emission rates because of the recent addition of pollution control devices. Also, high-annual-mileage autos deteriorate more rapidly and produce more emissions than low-mileage vehicles of the same model year. These two factors warrant the distinction between high- and low-annual mileage autos for the purpose of estimating vehicle emissions.

The breakdown of trucks into three groups is based upon test measurements of truck emission characteristics obtained by the U.S. Environmental Protection Agency (U.S. EPA) [Ref. 21].* Buses are divided into three groups because of the different travel patterns and fuel characteristics of vehicles in each group. Motorcycles exhibit distinct emission rates as indicated by the U.S. EPA [Ref. 6].

E.2 EMISSION FACTOR ESTIMATION PROCEDURE

Nitrogen oxides and hydrocarbons are byproducts of the combustion of automotive fuels and are emitted through the motor vehicle's exhaust system. In addition, gasoline-powered vehicles emit HC pollutants from the crankcase, the carburetor system, and the fuel system. Crankcase emissions result when incompletely burned gasoline passes out of the engine and is vented to the atmosphere. Late model autos are equipped with control devices that greatly reduce this source of pollution. The carburetor system experiences HC losses after the engine is shut down at the end of a trip, as fuel left in the carburetor evaporates. Evaporative emissions from the fuel system result when air in an incompletely filled fuel tank expands due to an increase in ambient air temperature. Such expansion occurs on a typical summer day and results in the expulsion of gasoline vapors to the atmosphere.

Crankcase and carburetor emissions occur as a result of vehicle operation and can be expressed as grams of HC emitted per mile traveled. Fuel system emissions are produced whether or not the vehicle is used and are expressed as grams per day per vehicle. Fuel system emissions will not be dealt with in this study because reduction of such emissions entails modification to vehicle design, and therefore, an episode regulation will not affect them.

The calculation of regional vehicle emission factors follows the U.S. EPA procedures [Ref. 21] along with modifications recommended by Cirillo and Wolsko [Ref. 5]. The auto emission factor, for example, is from the following equation:

*References are listed in Sec. E.7.

$$\text{Auto emissions (grams/mile)} = \sum_i \left\{ \begin{pmatrix}\text{exhaust emission}\\ \text{rate of } i^{th}\\ \text{model year autos}\end{pmatrix} + \begin{pmatrix}\text{crankcase and carbu-}\\ \text{retor emission rate of}\\ i^{th} \text{ model year autos}\end{pmatrix} \right\} \cdot \begin{pmatrix}\text{fraction of auto}\\ \text{Vmt by } i^{th} \text{ model}\\ \text{year vehicles}\end{pmatrix} \qquad (E.1)$$

where i is summed over all model years of vehicles in operation because of the differences in emission characteristics among model years. The second term in the summation is non-zero only for HC emissions from gasoline-powered vehicles, because carburetor and crankcase emissions do not occur in diesel engines, and NO_x is only found in the exhaust gases. Mathematically, Eq. E.1 is written as:

$$E_p(S,q,w) = \sum_i^N \left\{ E'_{ip} \cdot U_{ip}(S) \cdot Z_{ip}(q) \cdot R_{ip}(q,w) + E''_{ip} + E^*_{ip} \right\} \cdot m_i \qquad (E.2)$$

where:

$E_p(S,q,w)$ ≡ weighted average emission rate for automobiles in grams/mile for pollutant p; emissions depend on average vehicle speed S, ambient air temperature q, and percent cold operation w;

N ≡ number of model years of autos in operation;

E'_{ip}, E''_{ip}, E^*_{ip} ≡ the 1975 federal test procedure mean exhaust, crankcase, and carburetor emission factors, respectively, for automobiles of model year i, and for pollutant p;

$U_{ip}(S)$ ≡ emission speed correction factor for model year i and pollutant p at average speed S;

$Z_{ip}(q)$ ≡ temperature correction factor for model year i and pollutant p at ambient temperature q;

$R_{ip}(q,w)$ ≡ hot/cold vehicle operation correction factor for model year i, for pollutant p at ambient temperature q, and percent cold operation w; and

m_i ≡ fraction of auto miles due to model year i vehicles.

The temperature correction factor is approximately 1.0 for ambient temperatures between 68°F and 86°F. Since it is likely that an ozone episode would occur during the summer when temperatures fall in this range, the temperature correction factor is considered to be 1.0 throughout this analysis. Similarly, the hot/cold vehicle operation correction factor is assumed to be equal to the national figure of 1.0, because data specifically for the Chicago SMSA are not available. With $Z_{ip}(q)$ and $R_{ip}(q,w)$ both equal to 1.0, Eq. E.2 becomes:

$$E_p(S) = \sum_i^N \left(E'_{ip} \cdot U_{ip}(S) + E''_{ip} + E^*_{ip}\right) \cdot m_i \tag{E.3}$$

Equation E.3 is used to calculate emission factors for high- and low-annual-mileage autos using different annual mileage and vehicle age data. In addition, the effects of engine deterioration on emissions of high-mileage autos are taken into account by using a weighted average of present and projected values of the U.S. EPA emission factors for each model year. This procedure is analogous to the one recommended by Cirillo and Wolsko [Ref. 5]. For example, the high-mileage auto emission factors for 1974 model year cars are a composite of emission factors of 1974 autos in the years 1974, 1975, and 1976. The latter two emission factors take into account the effects of engine deterioration, resulting in slightly higher emission rates.

Equations similar to Eq. E.3 are used to estimate the regional truck emission factors. For transit buses the U.S. EPA city bus emission factors are applied [Ref. 21]. The emission factors calculated for heavy gasoline trucks are also used as the school bus emission factors since the U.S. EPA heavy truck emission factors apply to all types of heavy duty gasoline vehicles. Commercial buses include both gasoline- and diesel-powered vehicles. A composite emission factor is determined for this group using the following equation:

$$\overline{E}_p(S) = g \cdot E'_p(S) + h \cdot E''_p(S) \tag{E.4}$$

where:

$\overline{E}_p(S)$ ≡ commercial bus emission factor in grams/mile of pollutant p at average speed S,

$E'_p(S)$ ≡ regional emission factor for heavy gasoline trucks,

$E''_p(S)$ ≡ regional emission factor for diesel trucks, and

g, h ≡ fractions of commercial buses powered by gasoline and diesel fuel, respectively. The use of these factors assumes that the average daily mileage of gasoline buses is the same as that of diesel buses.

The emission factor for motorcycles is determined using:

$$\hat{E}_p = m \cdot E'_p + n \cdot E''_p \tag{E.5}$$

where:

$\hat{E}_p \equiv$ motorcycle average emission rate in grams/mile of pollutant p;

E'_p, $E''_p \equiv$ emission rate of 2-stroke and 4-stroke motorcycles, respectively, including emissions from the exhaust and crankcase; and

m, n $\equiv$ relative fractions of 2-stroke and 4-stroke motorcycles.

Note that the average emission factors given for motorcycles are not dependent upon speed.

E.3 EMISSION FACTOR ESTIMATES

The discussion of data in the ensuing paragraphs follows the framework developed in the previous section for calculating emission factors. All of the yearly vehicle emission data, including speed correction factors, are from U.S. EPA, AP-42, Supplement 5, except for motorcycles [Ref. 21]. Motorcycle data from another EPA document are used [Ref. 6]. Emission data applicable to the Chicago area come under the low altitude, non-California categories of these EPA publications. Continuous functions are given by the EPA to calculate speed correction factors between 15 mph and 45 mph; in addition, speed correction factors at 5 and 10 mph are presented. For speeds between 5 and 10 mph and between 10 and 15 mph, speed correction factors are determined by linear interpolation. Additional data required to calculate emission factors are presented in Table E.1. Because of the large number of these data, they are not reproduced here, but data sources are indicated.

Annual mileage and age data for passenger automobiles are used to calculate emission factors for the low-annual-mileage auto vehicle class, and taxi data are used to calculate emission factors for the high-annual-mileage auto vehicle class. An example of NO_x emission factor calculations for passenger automobiles is now given, based on Eq. E.3. Data are presented in Table E.2 assuming an average speed of 38.3 mph. The fraction of travel by model year i vehicles is equal to the product of the second and third columns (from the left) of Table E.2 for model year i, divided by the sum of the products of the same two columns for i equal to 1 through 13. For example, the fraction of travel by autos that are less than one year old is:

Table E.1. Additional Data for Emission Factor Calculations

Vehicle Class	Data	Source
Low-Annual-Mileage Auto	Vehicle Age Breakdown Annual Mileage by Model Year	Cirillo and Wolsko [Ref. 5] U.S. EPA [Ref. 21]
High-Annual-Mileage Auto	Vehicle Age Breakdown Annual Mileage by Model Year	Norco [Ref. 15] Norco [Ref. 15]
Light Gas Truck	Vehicle Age Breakdown Annual Mileage by Model Year	U.S. EPA [Ref. 21] U.S. EPA [Ref. 21]
Heavy Gas Truck	Vehicle Age Breakdown Annual Mileage by Model Year	U.S. EPA [Ref. 21] U.S. EPA [Ref. 21]
Heavy Diesel Truck	(Emission factors are the same for all model years so no additional information is needed)	
Transit Bus	(No additional information is needed)	
School Bus	(No additional information needed as heavy gas truck factors were used)	
Commercial Bus	Fractions of Vehicles Which are Gasoline and Diesel Powered	Federal Highway Administration [Ref. 9]
Motorcycle	Breakdown by 4-Stroke, 2-Stroke	U.S. EPA [Ref. 6]

$[0.1163 \cdot 15{,}900] \div [(0.1163 \cdot 15{,}900) + (0.1444 \cdot 15{,}000) + (0.1307 \cdot 14{,}000) + \ldots (0.0147 \cdot 6{,}700)] = 1849.17 \div 12{,}318.42 = 0.150$. Multiplying the fraction of travel for vehicles of each model year by the appropriate emission factor and speed correction factor of Table E.2 and summing over all model years, an average NO_x emission factor of 4.51 grams/mile is obtained.

The emission factors for several vehicle classes are illustrated in Figs. E.1 and E.2. The behavior of the emission factors with respect to speed is of interest. It is apparent that NO_x emission factors decrease as speed increases, at low speeds. At speeds of about 15 mph this trend is reversed with NO_x emissions increasing with speed. HC emissions decline as speed increases throughout the entire speed range.

As illustrated in Figs. E.1 and E.2, the relationships between emission factors and vehicle speed are highly nonlinear. Because of this fact, emission factors based on a single region-wide average traffic speed would be crude estimates. To resolve the problem, traffic must be divided into

Table E.2. Data for Low-Annual-Mileage Auto NO_x Emission Factor Calculation

Vehicle Age (years)	Fraction of Vehicles in Use[a]	Average Annual Mileage[b]	NO_x Emission Factor (grams/mile)[c]	Speed Correction Factor at S = 38.3[d]
<1	0.1163	15,900	3.1	1.151
1	0.1444	15,000	3.3	1.151
2	0.1307	14,000	4.55	1.151
3	0.1124	13,100	4.30	1.151
4	0.1090	12,200	4.35	1.151
5	0.1047	11,300	5.08	1.149
6	0.0815	10,300	4.32	1.080
7	0.0671	9,400	3.34	1.106
8	0.0523	8,500	3.34	1.183
9	0.0296	7,600	3.34	1.183
10	0.0230	6,700	3.34	1.183
11	0.0101	6,700	3.34	1.183
12	0.0042	6,700	3.34	1.183
13	0.0147	6,700	3.34	1.183

[a]Source: Ref. 5; Cook County passenger car data as of July 1, 1973.

[b]Source: Ref. 21; national data assumed to be applicable to the Chicago SMSA.

[c]Source: Ref. 21; latest model year emission factor is for 1974 vehicles.

[d]Based on data from Ref. 21.

homogeneous segments with respect to traffic speed. For example, expressway traffic and arterial traffic move significantly slower during peak (rush) hours than during off-peak hours. Each of these four traffic segments is characterized by an average traffic speed, and an emission factor for each of the nine vehicle classes can be determined for each traffic segment (expressway peak, expressway off-peak, arterial peak, arterial off-peak).

The speed data in Table E.3 were obtained from the Chicago Area Transportation Study (CATS) and used to calculate speed correction factors [Ref. 20]. Since emission factors are required at the off-peak expressway speed of 49.9 mph, the assumption was made that the EPA speed functions could be extended slightly beyond the range of 45 mph. The emission factors for all vehicle classes and traffic segments are presented in Tables E.4 and E.5. In Table E.4

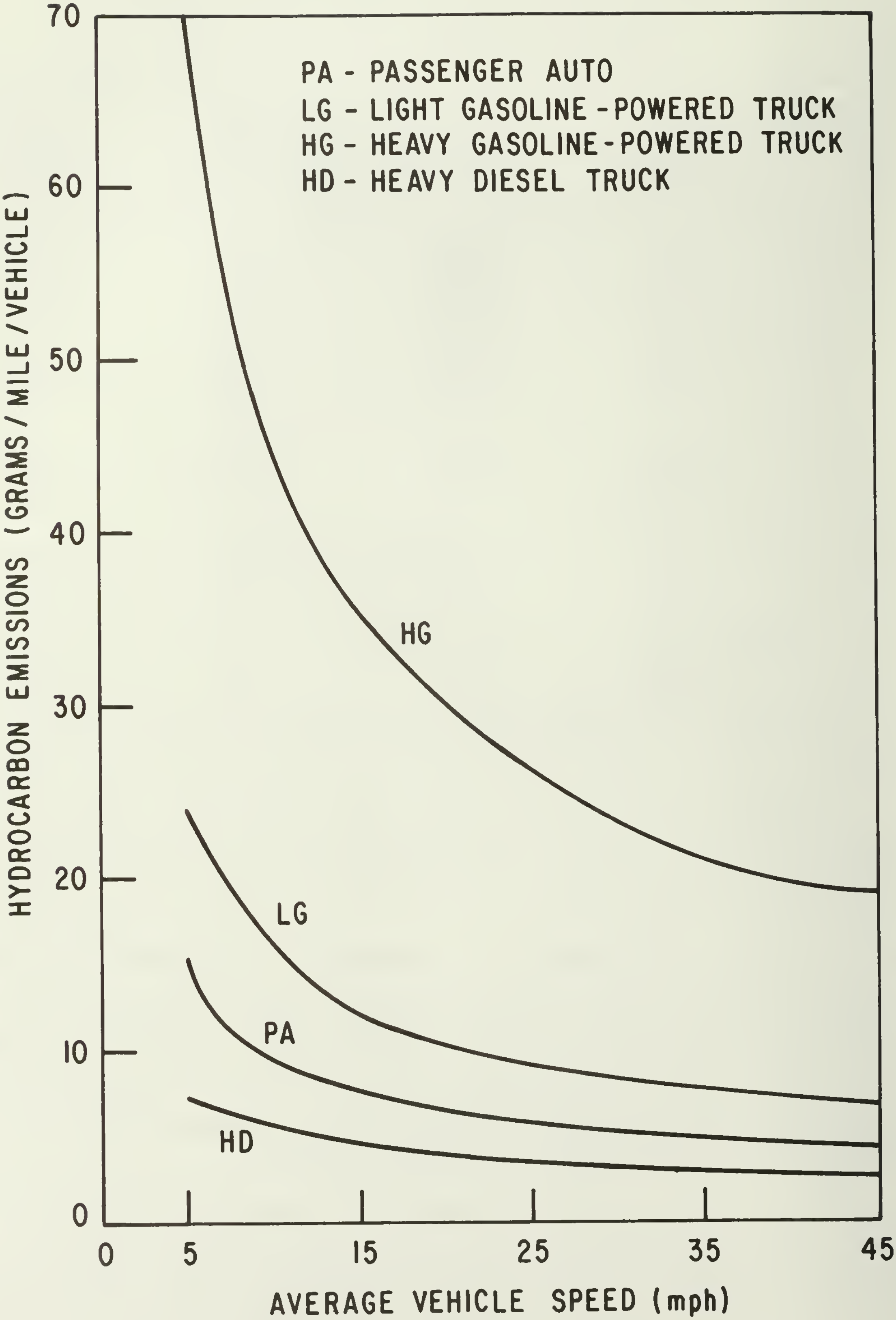

Fig. E.1. HC Emission Factors vs. Average Vehicle Speed

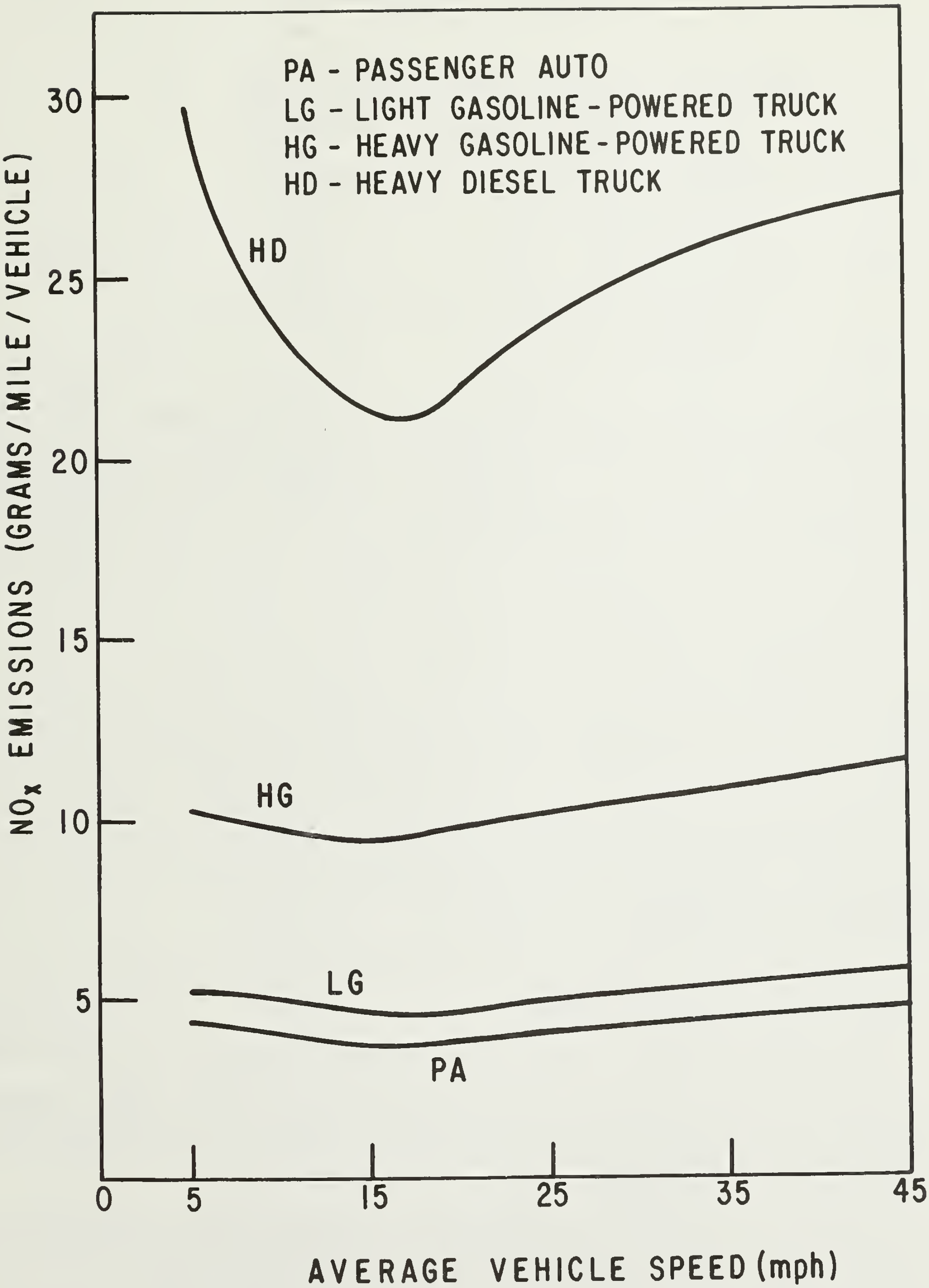

Fig. E.2. NO_x Emission Factors vs. Average Vehicle Speed

Table E.3. SMSA Speed Data

Traffic Segment	Average Traffic Speed (mph)
Expressway Peak	43.7
Expressway Off-Peak	49.9
Arterial Peak	11.9
Arterial Off-Peak	23.9

Source: Ref. 20.

it is observed that HC emissions decline for increasing speeds, as expected from Fig. E.1. From Table E.5 it is apparent that NO_x emissions for all vehicle classes except motorcycles increase between 11.9 and 23.9 mph and between 43.7 and 49.9 mph, as expected from Fig. E.2.

E.4 VEHICLE MILES TRAVELED

In this section, the vehicle miles traveled (Vmt) for the nine motor vehicle classes are estimated. Data collected in 1974 are not available in most cases; much of the data from the Chicago Area Transportation Study, particularly truck Vmt estimates, were collected in 1970. Because of the energy crisis and economic recession, traffic levels did not grow appreciably between 1970 and 1974. Therefore, no adjustment is made to pre-1974 data to estimate 1974 Vmt levels.

Low-Annual-Mileage Autos

Low-annual-mileage autos consist of cars averaging less than the arbitrarily chosen figure of 20,000 miles/year. Passenger autos, government autos for non-emergency services, ambulances, and autos in private fleets are included in this group.

Passenger auto Vmt is equal to the total daily Vmt of the SMSA minus Vmt due to all other traffic groups. Data from CATS indicate that total SMSA Vmt is approximately 92,977,470 miles/day [Ref. 17] excluding motorcycles. Total Vmt from traffic other than passenger autos is estimated at 10,134,970 miles/day by procedures discussed subsequently. Thus, the estimate of passenger auto travel is 82,842,500 Vmt/day.

Table E.4. HC Emission Factors by Vehicle Class and Traffic Segment

Vehicle Class	HC Emission Factors (grams/mile)			
	Arterial Peak (11.9 mph)[a]	Arterial Off-Peak (23.9 mph)[a]	Expressway Peak (43.7 mph)[a]	Expressway Off-Peak (49.9 mph)[a]
Low Mileage Auto	8.93	5.98	4.47	4.36
High Mileage Auto	8.26	5.42	4.04	3.94
Light Truck	13.85	9.38	6.96	6.78
Heavy Gas Truck	39.93	26.70	19.28	18.72
Heavy Diesel Truck	5.15	3.77	2.63	2.45
Transit Bus	4.48	3.28	2.28	2.13
School Bus	39.93	26.70	19.28	18.72
Commercial Bus	13.84	9.51	6.79	6.52
Motorcycle[b]	8.61	8.61	8.61	8.61

[a]Average speed for traffic segment.

[b]Motorcycle emission factor applies to all speeds.

Table E.5. NO_x Emission Factors by Vehicle Class and Traffic Segment

Vehicle Class	NO_x Emission Factors (grams/mile)			
	Arterial Peak (11.9 mph)[a]	Arterial Off-Peak (23.9 mph)[a]	Expressway Peak (43.7 mph)[a]	Expressway Off-Peak (49.9 mph)[a]
Low Mileage Auto	3.96	4.06	4.66	4.84
High Mileage Auto	3.93	4.05	4.68	4.87
Light Truck	4.82	4.95	5.70	5.93
Heavy Gas Truck	9.69	10.04	11.41	11.84
Heavy Diesel Truck	22.66	23.51	27.12	27.66
Transit Bus	23.31	24.19	27.90	28.45
School Bus	9.69	10.04	11.41	11.84
Commercial Bus	19.42	20.14	23.19	23.70
Motorcycle[b]	0.19	0.19	0.19	0.19

[a]Average speed for traffic segment.

[b]Motorcycle emission factor applies to all speeds.

Data on the number of government non-emergency autos in the SMSA are presented in Table E.6. It is estimated that there are 6,813 federal, state, county, and municipal autos in the SMSA, excluding police cars. An average annual mileage figure of 20,000 miles is given by Norco, et al. [Ref. 15] as appropriate for vehicles in this group. Norco surveyed several large fleet owners and government operators. Conversations with government agencies have tended to confirm this estimate. Using these data, government non-emergency auto Vmt is estimated as: (6,813 vehicles)•(20,000 miles per year per vehicle)/(365 days per year) = 373,315 miles/day.

Ambulance Vmt is estimated as follows. There are 563 vehicles with ambulance licenses in the state of Illinois [Ref. 2]. Assuming that the ambulances are distributed homogeneously with respect to population, 63% operate in the SMSA. Applying a rough estimate of 15,000 miles per year per ambulance, the daily ambulance Vmt is: [(563•0.63) vehicles]•[15,000 miles per year per vehicle]/[365 days per year] = 14,576 miles/day. Since this number is small relative to total automobile Vmt, an effort to obtain a precise estimate of annual mileage was not carried out for determining the total vehicle emissions breakdown. However, for a particular action this information may become important enough to warrant further data collection efforts.

Information on utility vehicle travel was obtained from Northern Illinois Gas Company;* People's Gas, Light and Coke Company;* and Commonwealth Edison Company.† From these data, daily auto Vmt for these fleets is estimated to be 74,543. Many small private automobile fleets also exist. To acquire information on them would entail an extensive effort for what would apparently be a very small number relative to total Vmt. For this reason fleet auto Vmt is assumed to be double the above number, or 149,086 miles/day.

High-Annual-Mileage Autos

Automobiles in the high-annual-mileage group are taxis and police cars. Taxi Vmt is estimated from the equation:

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*Data obtained through phone interviews.

†The Commonwealth Edison estimate is based on the testimony of Mr. Bide Thomas on May 5, 1975. Mr. Thomas states that Edison operates 1,320 cars in its fleet. It is assumed that 85% of this activity is in the SMSA and the annual mileage of these vehicles is 16,000 miles.

Table E.6. Government Non-Emergency Autos

Type of Agency	Number of Autos
Municipal[a]	3,301
County[b]	449
State[c]	1,021
Federal	
With Illinois License[d]	369
Post Office[e]	23
General Service Administration[f]	700
All Other Agencies[g]	950
TOTAL	6,813

[a]There are 8,121 municipality-owned autos in the SMSA [Ref. 1]. Of these it is estimated that 4,820 are municipal police cars, based on conversations with a sample of municipal police officials. Excluding police cars, non-emergency municipal autos are estimated at 3,301.

[b]Estimate is based on conversations with officials of the six SMSA counties.

[c]There are 1,412 state-owned autos in the SMSA [Ref. 1]. Of these it is estimated that 391 are police cars, based on a conversation with state police. Excluding police cars, non-emergency state-owned autos are estimated at 1,021.

[d]Ref. 1.

[e]Ref. 8.

[f]Ref. 7.

[g]There are approximately 95 federal agencies in the SMSA according the the Chicago Federal Executive Board. It is assumed that an average of 10 cars are used per agency.

$$\text{Vmt} = (\text{No. of passenger trips})\cdot(\text{trip length}) \div(\text{fraction of trips with passengers})$$

Recently collected data indicates there are 156,849 daily passenger trips in the SMSA with an average trip length of 2.78 miles [Ref. 19]. It is estimated that taxis operate with passengers 50% of the time [Ref. 3] Combining this information yields: Vmt = (156,849 trips per day)•(2.78 miles per trip)/0.50 = 872,080 miles/day.

A survey of state, county, and municipal law enforcement organizations was conducted to obtain police car mileage data. Annual figures were divided by 365 to arrive at daily Vmt estimates; this information is summarized in Table E.7. The Vmt estimate for municipal police departments excluding Chicago is based on telephone surveys. Police car fleet mileage data for a cross section of communities were obtained. The 14 municipalities surveyed included 13.5% (492,151 persons) of the SMSA population, excluding Chicago. For these communities, police car Vmt averaged 18.3 miles per person per year. From conversations with police officials it was found that decisions on the acquisition of vehicles are based on population and geographical size. Since communities having a cross section of size were sampled, police car Vmt extrapolated by population should be a reasonable estimate. Applying the survey results to the SMSA provides this estimate of municipal police car Vmt excluding Chicago: Vmt = (18.3 miles per person per year)•(3,611,990 SMSA population excluding Chicago)/(365 days per year) = 181,094 miles/day. Thus, as shown in Table E.7, state, county, and municipal police agencies compile an estimated 431,724 Vmt per day.

Table E.7. Daily Police Car Vmt

Organizations	Vmt (miles/day)
State Police in SMSA	21,431
Six County Sheriff Depts.	53,857
Chicago PD	175,342
All Other Municipalities (Estimated)	181,094
TOTAL	431,724

Trucks

All of the data on Truck Vmt is based on studies by CATS [Ref. 23]. This is aggregate truck Vmt due to commercial, private, and government vehicles.* A problem arises in the compatibility of CATS truck categories with the framework set up in this analysis. Four truck categories are defined by CATS: light, medium, heavy, and unclassified. A light truck is defined as a single unit vehicle with two axles (roughly less than 36,000 lbs GVW). A medium truck is a single unit truck having three axles (36,000-50,000 GVW). Heavy trucks include single unit trucks with four or more axles and semi-trailer, full trailer, and truck trailer combinations (over 50,000 GVW). The unclassified group consists of all trucks with non-Illinois and non-Indiana license plates regardless of size.

To calculate vehicle emissions, categories need to be broken down into the light gasoline, heavy gasoline, and heavy diesel classes used in this study. Another compatibility problem stems from the fact that the CATS study area includes Porter and Lake counties in Indiana along with the six SMSA counties in Illinois. In some cases, data on Illinois alone are not easily separated. With these problems in mind, the method used to convert the CATS data is now discussed.

Truck Vmt data from CATS are shown in Table E.8. The internal trip category in Table E.8 refers to trips which occur entirely within the area,

Table E.8. Truck Vmt

	Vmt by CATS Truck Category (miles/day)			
Trip Type	Light	Medium	Heavy	Unclassified
Internal (SMSA)	3,976,694	603,278	1,300,073	0
External (eight county)	309,540	42,480	485,080	1,105,440

Source: Ref. 23.

*Although the CATS data were collected in 1970, it is assumed that truck Vmt did not grow appreciably between 1970 and 1974 due to economic recession and the energy crisis. CATS indicates that this was the case for overall Vmt.

in this case the Illinois portion of the CATS study area. External truck trips consist of inbound and outbound trips and movements through the region, in this case the entire eight-county region. The problem is one of estimating the Illinois portion of external Vmt. Internal six-county Vmt represents 89.5%, 96.4%, and 90.4% of eight-county internal Vmt (not shown in Table E.8) for light, medium, and heavy trucks, respectively.* These internal percentages are applied to the eight-county data to estimate the six-county external component. Based on a statement by CATS that unclassified trucks consist predominantly of heavy trucks [Ref. 23], the assumption is made that 90% of the Vmt by unclassified trucks is due to heavy trucks and 10% of the Vmt is due to medium trucks. External six-county Vmt estimates are then 277,038 for light trucks, 151,495 for medium trucks, and 1,433,408 for heavy trucks. The total SMSA truck Vmt is then equal to 4,253,732 for light trucks, 754,733 for medium trucks, and 2,733,481 for heavy trucks.

CATS data reveal that 70.2% of the miles traveled by vehicles in the internal light truck category is by trucks of less than 8,500 pounds GVW [Ref. 24]. Assuming that this factor applies to external light truck Vmt as well, daily travel by trucks of less than 8,500 pounds GVW is $4,253,732 \cdot (0.702) = 2,986,120$ Vmt. On fuel breakdown, sampling data reveal that 95.6% of medium trucks are gasoline powered and the rest are diesel [Ref. 17]. This amounts to a 721,563/33,210 gasoline-diesel split in medium truck Vmt. With CATS heavy truck sample data it is estimated that 34.2% of heavy truck Vmt is due to gasoline powered trucks [Ref. 17]. This amounts to a 934,851/1,798,630 gasoline-diesel split in heavy truck Vmt. Heavy duty gasoline Vmt is then equal to $721,563 + 934,851 + 1,267,612 = 2,924,026$, where the last term is Vmt by trucks in the CATS light truck category of over 8,500 lbs GVW. Heavy duty diesel Vmt is equal to $33,210 + 1,798,630 = 1,831,840$ miles/day.

Buses

Data from the Regional Transportation Authority (RTA) indicate that Chicago Transit Authority (CTA) buses compile approximately 271,000 miles/day and suburban transit buses travel 38,130 miles/day [Ref. 10]. The total transit bus Vmt for the SMSA is then estimated at 309,130 miles/day. The vast majority of CTA buses are diesel powered [Ref. 3]. The assumption is made that all transit buses in the area are diesel powered.

*Based on data in Ref. 23.

School bus passenger-miles-traveled (PMT) for the six counties amount to 1,368,750 PMT/day [Ref. 18]. Converting to Vmt by dividing by an average load factor of 16.8 persons per bus [Ref. 4] (assumed here to apply to school buses as well as transit buses), the daily school bus estimate is 81,473 Vmt. This number applies to days when school is in full session. During the summer approximately 18% of the students in the SMSA attend school [Ref.22]. Assuming a proportional decrease in school bus Vmt yields a summer figure of 14,665 miles/day. When calculating total vehicle emissions, the full session school bus Vmt is employed.

Commercial bus data were obtained only on a state-wide basis. In 1972, there were 6,400 commercial buses registered in Illinois, including transit buses [Ref. 9]. Excluding the 3,900 transit buses in the state [Ref. 11], it is estimated that 2,540 commercial buses are in operation. It is assumed that these commercial buses are distributed homogeneously across the state with respect to population. Since 63% of the state's population is in the SMSA, an estimate of 2,540 • 0.63 = 1,600 commercial buses is made for the SMSA. Registration data on the 6,440 commercial buses indicate that 24% were gasoline powered and 76% were diesel powered [Ref. 9]. If it is assumed that the average daily Vmt for a commercial bus is equal to the CTA daily Vmt of 101 miles per bus [Ref. 4], then the Vmt for commercial gasoline buses is equal to 1,600 • 101 = 161,600 miles/day, of which 24% is due to gasoline-powered buses and 76% to diesels.

Motorcycles

In 1975 there were 94,155 motorcycles registered by the public in the SMSA [Ref. 12]. The average annual mileage for motorcycles in 1974 nationwide was 4,500 miles [Ref. 13]. This national figure includes the southern U.S. where motorcycles are driven for the entire year, as well as the northern U.S. where motorcycles are driven only 8 or 9 months of the year. Assuming motorcycles are driven a national average of 10 months during the year, they would accrue mileage during the months they were in use at the rate of 450 miles per month. Dividing by 30 days per month, the estimated daily motorcycle mileage is 15 miles. Motorcycle Vmt for the SMSA is then equal to 94,155 • 15 = 1,412,325 miles/day.

Estimates of Vmt by vehicle class are summarized in Table E.9.

Table E.9. Daily Motor Vehicle Vmt

Vehicle Class	Daily Vmt
Low Mileage Auto	
Passenger	82,842,500
Other	536,977
High Mileage Auto	1,303,804
Light Gasoline Truck	2,986,120
Heavy Gasoline Truck	2,924,026
Heavy Diesel Truck	1,831,840
Transit Bus	309,130
School Bus	81,473
Commercial Bus	161,600
Motorcycle	1,412,325
TOTAL	94,389,795

E.5 TRAVEL CHARACTERISTICS AND APPORTIONMENT TO TRAFFIC SEGMENTS

Passenger Auto Travel

A breakdown of national passenger auto Vmt by purpose is provided in Table E.10. Such a trip purpose breakdown for the SMSA is desirable, but not available. A trip destination breakdown for passenger autos, which is similar to a trip purpose breakdown, for the Chicago region is shown in Table E.11. The trip destination breakdown differs from the trip purpose breakdown mainly in that the "home" category is included. Home travel must be broken down by original trip purpose. Some trips are linked trips, such as home-work-shopping-home, rather than direct trips, such as home-work-home. Because of this, the Vmt for home trips is less than 50%, and a simple doubling of Vmt for trips with destinations other than home will not produce an accurate home trip breakdown by purpose. Table E.12 contains the assumptions made in converting the home Vmt to original trip purpose Vmt as well as the resulting breakdown.

Since these assumptions result in an estimate of the regional Vmt breakdown that is similar to the national data,* it is felt that the estimated regional trip purpose breakdown is accurate and will be used in the remainder of this study.

*The largest discrepancy is in shopping trips.

Passenger auto travel must be further broken down by traffic segment for emission calculations. It is assumed that the vast majority of work trips, 85%, occur during the peak hours of 6-9 a.m. and 4-6 p.m.;* the remainder occurs during the off-peak hours. Fifty percent of school trips occur in the morning peak period. The remaining 50% return home trips occur during the off-peak mid-afternoon period. The number of trips for purposes

Table E.10. National Passenger Auto Travel by Purpose[a]

Trip Purpose	% of Vmt
Work	32.9
Work-Related Business	7.7
Shopping	7.6
Educational, Civic, and Religious	4.9
Social/Recreational	33.3
Family Business Excluding Shopping	12.4
Other or Not Available	1.2
TOTAL	100.0

[a]Based on Ref. 14.

Table E.11. Regional Passenger Auto Travel by Destination

Trip Destination	% of Vmt[a]
Home	41.9
Work	21.1
Work-Related	6.6
Shopping	7.8
School	0.6
Social/Recreational	13.1
Personal Business	5.9
Other	3.0
TOTAL	100.0

[a]Based on passenger auto trip data, and trip length data by purpose from Ref. 16.

*Peak hours are so defined to be compatible with the average speed data obtained from CATS.

Table E.12. Estimated Regional Trip Purpose Breakdown

Trip Purpose	Assumption	Modified % Vmt
Work	70% of trips from work have home as direct destination.	21.1 • 1.70 = 35.9
Work-Related	No work-related trips have home as destination.	6.6
Shopping	75% of shopping trips are direct home-shop-home trips.	7.8 • 1.75 = 13.7
School	All school trips are direct home-school-home trips.	0.6 • 2 = 1.2
Social/Recreational	All social/recreational trips are direct home-sr-home trips.	13.1 • 2 = 26.2
Personal Business	75% of personal business trips are home-pb-home trips.	5.9 • 1.75 = 10.4
Other	All other trips are direct home-other-home trips	3.0 • 2 = 6.0
TOTAL		100.0

other than work and school during the peak hours is relatively insignificant. It is also assumed that passenger auto Vmt for each trip is divided between arterials and expressways in the same proportions as total Vmt. The CATS data reveal that out of 92,977,470 total Vmt, 24,054,120 (25.9%) occurs on expressways and 68,923,350 (74.1%) occurs on arterials [Ref. 17].

The passenger auto Vmt is divided into traffic segments as illustrated in Table E.13. Combining the data of Tables E.12 and E.13, a total breakdown of passenger auto Vmt is shown in Table E.14.

Non-Passenger Auto Vehicle Classes

Based on hourly trip data it is estimated that 29.1% of truck Vmt is during peak hours and 70.9% during off-peak hours.* Applying the expressway/arterial breakdown of 25.9/74.1 to these truck figures the resulting four-way

*This breakdown is based on a profile of internal and external truck trip volumes by time-of-day graphs appearing in Ref. 23.

Table E.13. Passenger Auto Vmt by Traffic Segment

Trip Purpose	Vmt Breakdown by Traffic Segment (%)				
	Expressway Peak	Expressway Off-Peak	Arterial Peak	Arterial Off-Peak	Total
Work	22.0	3.9	63.0	11.1	100
Work-Related	0	25.9	0	74.1	100
Shopping	0	25.9	0	74.1	100
School	13.0	13.0	37.0	37.0	100
Social/Recreational	0	25.9	0	74.1	100
Personal Business	0	25.9	0	74.1	100
Other	0	25.9	0	74.1	100

Table E.14. Breakdown of Total Passenger Auto Vmt

Trip Purpose	Total Vmt Breakdown by Traffic Segment (%)				
	Expressway Peak	Expressway Off-Peak	Arterial Peak	Arterial Off-Peak	Total
Work	7.9	1.4	22.6	4.0	35.9
Work-Related	0	1.7	0	4.9	6.6
Shopping	0	3.5	0	10.2	13.7
School	0.2	0.2	0.4	0.4	1.2
Social/Recreational	0	6.8	0	19.4	26.2
Personal Business	0	2.7	0	7.7	10.4
Other	0	1.6	0	4.4	6.0
TOTAL	8.1	17.8[a]	23.1[a]	51.0	100.0

[a]Column figures do not add to totals because of round-off errors.

truck Vmt fractional split is 0.075/0.184/0.216/0.525. Transit buses operate almost entirely on arterials [Ref. 10] and are assumed to have a four-way split of 0/0/0.309/0.691. The assumption is made that 50% of school bus travel is during the morning peak hours and the remaining 50% is made during mid-afternoon off-peak hours. The resulting split is 0.130/0.130/0.370/0.370.

Average hourly traffic data for arterials and expressways were obtained from CATS from which the peak and off-peak portions could be calculated. It is estimated that 29.1% of expressway traffic and 30.9% of arterial traffic occurs during the peak hours; the remainder is off-peak. Combining this

information with the expressway/arterial split of 25.9/74.1, the breakdown obtained for general traffic is 0.075/0.184/0.229/0.512. This breakdown is used for vehicle classes for which specific data were not available.

Table E.15 summarizes the traffic segment breakdown for non-passenger auto vehicle classes. The Vmt data in Table E.9 are broken down by traffic segment and presented in Table E.16.

E.6 TOTAL VEHICLE EMISSIONS

Total motor vehicle emissions are determined by applying the appropriate emission factor to the Vmt of each vehicle class and summing over the four traffic segments. Total vehicle emissions are estimated with the following equation:

$$T_p = \sum_{j=1}^{4} \sum_{i=1}^{9} V_{ij} \cdot E_{pi}(S_j)/907{,}184 \qquad \text{(E.6)}$$

where:

T_p ≡ total motor vehicle emissions of pollutant p (tons/day);

p ≡ pollutant: 1 = hydrocarbons, and 2 = nitrogen oxides;

j ≡ traffic segment: 1 = expressway peak hours, 2 = expressway off-peak hours, 3 = arterial peak hours, and 4 = arterial off-peak hours;

i ≡ vehicle classes;

V_{ij} ≡ daily Vmt by class i vehicles during period j;

$E_{pi}(S_j)$ ≡ emission factor for vehicle class i of pollutant p at average speed S_j (grams/day); and

The constant 1/907,184 converts grams to tons.

For example, from Table E.4, HC emission factors for passenger automobiles are 4.47, 4.36, 8.93 and 5.98 grams/mile for the expressway peak, expressway off-peak, arterial peak, and arterial off-peak traffic segments, respectively. The passenger auto data in Table E.16 shows $6.71 \cdot 10^6$, $14.7 \cdot 10^6$, $19.1 \cdot 10^6$, and $42.3 \cdot 10^6$ miles driven in each of these traffic segments, respectively. Substituting these data in Eq. E.6 provides an estimate of HC emissions from passenger autos of:

$$\begin{aligned}\text{Auto HC Emissions} &= [(6.71 \cdot 10^6)\cdot 4.47 + (14.7 \cdot 10^6)\cdot 4.36 \\ &\quad + (19.1 \cdot 10^6)\cdot 8.93 + (42.3 \cdot 10^6)\cdot 5.98]/907{,}184 \\ &= 571 \text{ tons/day.}\end{aligned}$$

Table E.15. Non-Passenger-Auto Breakdown by Traffic Segment

Vehicle Class	Vmt Breakdown by Traffic Segment (%)			
	Expressway Peak	Expressway Off-Peak	Arterial Peak	Arterial Off-Peak
Non-Passenger Auto	7.5	18.4	22.9	51.2
High Mileage Auto	7.5	18.4	22.9	51.2
Light Gasoline Truck	7.5	18.4	21.6	52.5
Heavy Gasoline Truck	7.5	18.4	21.6	52.5
Heavy Diesel Truck	7.5	18.4	21.6	52.5
Transit Bus	0	0	30.9	69.1
School Bus	13.0	13.0	37.0	37.0
Commercial Bus	7.5	18.4	22.9	51.2

Table E.16. Vmt Breakdown by Traffic Segment

Vehicle Class[a]	Vmt by Traffic Segment (10^3 miles/day)				
	Expressway Peak	Expressway Off-Peak	Arterial Peak	Arterial Off-Peak	Total[b]
Low Mileage Auto					
Passenger	6,710	14,746	19,137	42,250	82,843
Other	40	99	123	275	537
High Mileage Auto	98	240	299	668	1,305
Light Gasoline Truck	224	549	645	1,568	2,986
Heavy Gasoline Truck	219	538	632	1,535	2,924
Heavy Diesel Truck	137	337	396	962	1,832
Transit Bus	0	0	96	214	310
School Bus	11	11	30	30	82
Commercial Bus	12	30	37	83	162
TOTAL	7,451	16,550	21,395	47,585	92,981[c]

[a]Motorcycle Vmt is not broken down by traffic segment because motorcycle emission factors are averages for all speeds.

[b]Numbers in this column may be slightly different than numbers in Table E.9 due to rounding errors.

[c]Does not add to 92,977 because of rounding errors.

Table E.17. SMSA Motor Vehicle Emissions Breakdown

Vehicle Class	Daily Vmt 10^3 Miles	Daily Vmt %	NO_x Emissions Tons/Day	NO_x Emissions %	HC Emissions Tons/Day	HC Emissions %
Low Mileage Auto						
Passenger	82,843	87.8	386.0	76.1	570.9	78.2
Other	537	0.6	2.5	0.5	3.7	0.5
High Mileage Auto	1,304	1.4	6.1	1.2	8.2	1.1
Light Truck	2,986	3.2	17.0	3.3	31.9	4.4
Heavy Gas Truck	2,924	3.1	33.5	6.6	88.7	12.2
Heavy Diesel Truck	1,832	1.9	49.2	9.7	7.6	1.0
Transit Bus	309	0.3	8.1	1.6	1.2	0.2
School Bus	81	<0.1	0.9	0.2	2.7	0.4
Commercial Bus	162	<0.2	3.7	0.7	1.7	0.2
Motorcycle	1,412	1.5	0.3	0.1	13.4	1.8
TOTAL	94,390	100.0	507.3	100.0	730.0	100.0

The Vmt data of Table E.16 and the emission factor data of Tables E.4 and E.5 were combined according to Eq. E.6 to estimate daily motor vehicle emissions. The results of these calculations are presented in Table E.17. It is estimated that an average of 507.3 tons/day of NO_x and 730.0 tons/day of HC are produced by motor vehicles in the SMSA, excluding HC evaporative emissions from fuel tanks. Note that passenger autos account for the largest portion of Vmt as well as HC and NO_x emissions.

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APPENDIX F: ESTIMATING THE SPEED EFFECTS OF VMT REDUCTIONS

The speed data presented in Table E.3 indicate that average traffic speeds during the peak hours (6-9 a.m. and 4-6 p.m.) for arterials and expressways are much lower than during the off-peak hours. It is likely that a reduction in peak-hour traffic congestion would result in an increase in traffic speed for the period. The object of this appendix is to construct a quantitative relationship between traffic volume reduction and speed increase.

The following simplifying assumptions are made:

1. The average speed of off-peak traffic is constrained by speed limits and traffic signals rather than traffic congestion. This implies that a reduction in off-peak Vmt does not result in a speed increase of the remaining traffic.
2. The average speed of peak-hour traffic is limited by congestion. In this case a reduction of off-peak Vmt results in a speed increase of the remaining traffic.

These assumptions imply that if peak-hour congestion was reduced sufficiently, the average speed of peak traffic would increase to the average speed of off-peak traffic. The problem is one of defining a measure of congestion. It is assumed that congestion can be characterized as an average traffic flow rate. For example, arterial peak-hour Vmt is estimated to be 21,393,000 for a five-hour period (see Table E.16). The average flow rate is 4,278,600 Vmt/hr at an average speed of 11.9 mph. The off-peak Vmt is 47,585,000 for a 19-hour period, and the average flow rate is 2,504,474 Vmt/hr at an average speed of 23.9 mph. Thus, two end points of a curve of average speed versus flow rate have been established, as illustrated in Fig. F.1. Since only the two end points of this functional relationship can be determined from the data, the shape of the curve is unknown. The assumption is made that a straight line connects the two points. The relationship for arterials in Fig. F.1 is given by Eq. F.1, which is referred to as the arterial peak speed adjustment equation:

$$\text{Arterial Average Speed} = -6.764 \times 10^{-6}\ (\text{Av. Vmt/hr}) + 40.840 \qquad (\text{F.1})$$

An example will illustrate the usefulness of Eq. F.1. If peak-arterial Vmt was reduced by 5×10^6, the remaining Vmt would be 14.5×10^6 for an average flow rate of 2.9×10^6 Vmt/hr. The corresponding new traffic speed at

this flow rate, from Eq. F.1, would be equal to $(-6.764 \times 10^{-6})\cdot(2.9 \times 10^{6}) + 40.480 = 21.2$ mph. This speed can then be used to calculate the corresponding change in emissions.

For expressway traffic, the end points of a speed/congestion equation and the data used to estimate the points for expressway traffic are given in Table F.1. The resulting speed flow rate function for expressways also is shown in Fig. F.1. The relationship is described in Eq. F.2, which is referred to as the expressway peak speed adjustment equation:

$$\text{Expressway Average Speed} = -1.001 \times 10^{-5} \text{ (Ave. Vmt/hr)} + 58.623 \quad \text{(F.2)}$$

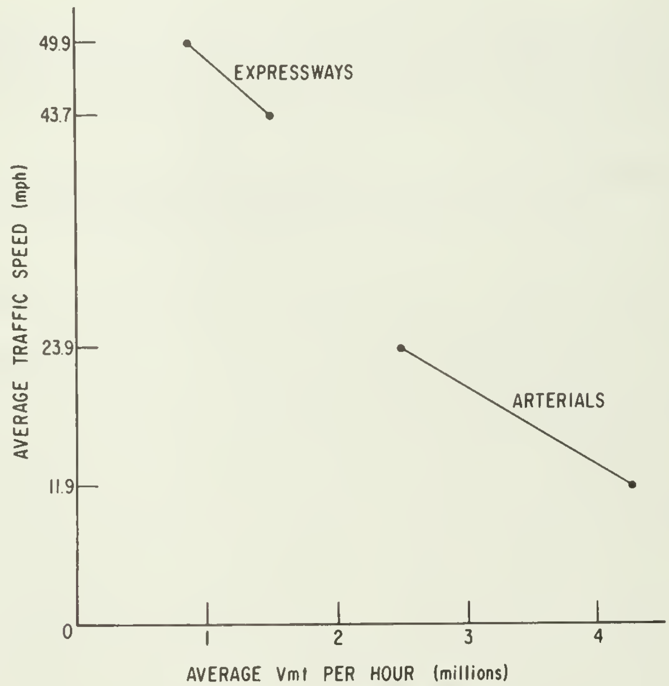

Fig. F.1. Speed Adjustment Functions

Table F.1. Expressway Flow Data

Period	Hrs	Vmt	Vmt/hour	Ave. Speed
Peak	6-9 am 4-6 pm	7,451,000	1,490,200	43.7 mph
Off-Peak	9-4 pm 6-6 am	16,550,000	871,053	49.9 mph

APPENDIX G: EVAPORATIVE HYDROCARBON EMISSIONS FROM THE SALE OF GASOLINE*

Whenever vehicular traffic is curtailed the average quantity of gasoline sold will decrease, resulting in decreased evaporative hydrocarbon emissions. The reduction in HC emissions is estimated as:

$$\overline{R} = \sum_{i=1}^{9} (V_i/M_i)\cdot E \qquad \text{(G.1)}$$

where:

$\overline{R}$ ≡ reduced evaporative hydrocarbon emissions (ton/day),

i ≡ vehicle class (see Appendix E),

V_i ≡ reduction in vehicle miles traveled by class i vehicles (Vmt/day),

M_i ≡ average fuel use efficiency of vehicles in class i (miles/gal.), and

E ≡ average HC emission per gallon of gasoline sold (tons/gal.).

Equation G.1 is based on the fact that the average quantity of gasoline sold each day is equal to the average quantity of gasoline consumed each day.

The daily vehicle miles traveled by each of the nine vehicle classes (low-mileage and high-mileage automobile Vmt have been aggregated), the values of M_i, and the resulting estimate of the average quantity of gasoline sold each day in the Chicago SMSA are presented in Table G.1. From Ref. 2** the evaporative emissions from the filling of motor vehicle fuel tanks are 11.0 lbs/10^3 gal. pumped, the emissions from liquid spillage losses are 0.67 lb/10^3 gal. pumped, and the evaporation loss from the service station storage tank is 1.0 lb/10^3 gal. pumped. Therefore:

$$E = (11.0 + 0.67 + 1.0)/(2 \cdot 10^6) = 6.335 \cdot 10^{-6} \text{ ton/gal.}$$

This emission factor is assumed appropriate for all vehicle types and meteorological conditions. Applying this emission factor to the average daily consumption of gasoline provided in Table G.1 results in expected evaporative HC emissions of 47.90 tons/day without any episode controls.

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*In this appendix, "gasoline" refers to gasoline and diesel fuels.

**References are listed at the end of this appendix.

Table G.1. Motor Vehicle Fuel Consumption in the Chicago SMSA

Vehicle Type	Vmt/Day[a]	Miles/Gal.	Gal./Day[b]
Low- and High-Mileage Autos	84,683,281	13.6[c]	6,226,712
Light Gasoline Trucks	2,986,120	10.0[c]	298,612
Heavy Gasoline Trucks	2,924,026	6.0[c]	487,338
Heavy Diesel Trucks	1,831,840	4.6[c]	398,226
Transit Buses	309,130	3.6[d]	85,869
School Buses	81,473	6.0[e]	13,579
Commercial Buses	161,600	6.0[e]	26,933
Motorcycles	1,412,325	60.0[f]	23,539
TOTAL	94,389,795	12.5[g]	7,560,808

[a]Vmt estimates from Appendix E.

[b]Calculated by dividing miles/day by miles/gal.

[c]From Ref. 3.

[d]From Ref. 1, assuming CTA miles/gal. data are applicable to all transit buses in the region.

[e]The heavy gasoline truck figure is assumed to also apply to school and commercial buses.

[f]Assumed value.

[g]Average.

The Vmt reductions resulting from each episode control action, i.e., the values of V_i in Eq. G.1, are provided in Table G.2. The evaporative HC emission reductions resulting from each action are estimated using Eq. G.1 and are given in the last column of Table G.2.

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Table G.2. Vehicle Miles Traveled and Evaporative HC Emission Reduction of the Episode Control Actions

Action Number & Chapter Number	Vehicle Mile Reductions (Vmt/day) Low Mileage Autos[a]	High Mileage Autos	Light Gasoline Trucks	Heavy Gasoline Trucks	Heavy Diesel Trucks	Transit Buses	School Buses	Commercial Buses	Motor-cycles	Gallons of Gasoline Saved (gal./day)	Evaporative HC Emission Reduction (tons/day)
1 (3)[a]	4,659,291	--	20,657	--	--	--	--	--	--	344,661	2.18
7 (9)	137,949	810,162	620,288	2,005,258	1,256,251	--	--	--	--	739,051	4.68
8 (10)	16,140,635	--	--	--	--	--	--	--	--	1,186,811	7.52
10 (12)	1,695,536	--	--	--	--	--	--	--	--	124,672	0.790
14 (16)	978,005	--	87,434	67,972	35,057	--	--	--	--	99,605	0.631
15 (17)	959,232	--	--	--	--	--	35,212	--	--	76,400	0.484[c]
16 (18)	--	--	--	--	27,972	--	--	--	--	6,081	0.0385
17 (19)	--	--	--	--	24,000	--	--	--	--	5,217	0.0330
18 (20)	83,676,303	--[b]	2,968,020	2,916,006	1,831,840	309,130	81,473	161,600	1,412,325	7,483,619	47.4
19 (21)	593,041	110,668	--	112,776	--	20,891	--	--	--	76,342	0.484
20 (22)	8,879,474	--[b]	--	--	--	--	--	--	--	652,903	4.14
22 (24)	46,037,151	--[b]	1,578,034	1,372,390	546,988	--	--	--	--	3,890,530	24.6
Yellow Alert	4,659,291	--	20,657	--	--	--	--	--	--	344,661	2.18
Red Alert	19,911,357	810,162	678,870	2,050,799	1,279,738	--	35,212	--	--	2,217,401	14.0
Emergency	83,676,303	--[b]	2,968,020	2,916,006	1,831,840	309,130	81,473	161,600	1,412,325	7,483,619	47.4

[a] Some of the Vmt reduction assigned to automobiles may actually be motorcycle Vmt reductions. For simplicity we usually did not consider motorcycle Vmt reduction. However, this simplification results in an insignificant error because of the limited use of motorcycles.

[b] Included in low-mileage automobile Vmt reductions.

[c] When school is in full session, the HC reduction is 1.12 tons/day. When school is in summer session, it is .202 tons HC/day. The expected reduction is 1.12 (.38) + .202 (.29) = .484 tons HC/day.

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